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Remote sensing in forest damage detection and appraisal

Selected annotated bibliography

Philip [illegible]mbarzevsky

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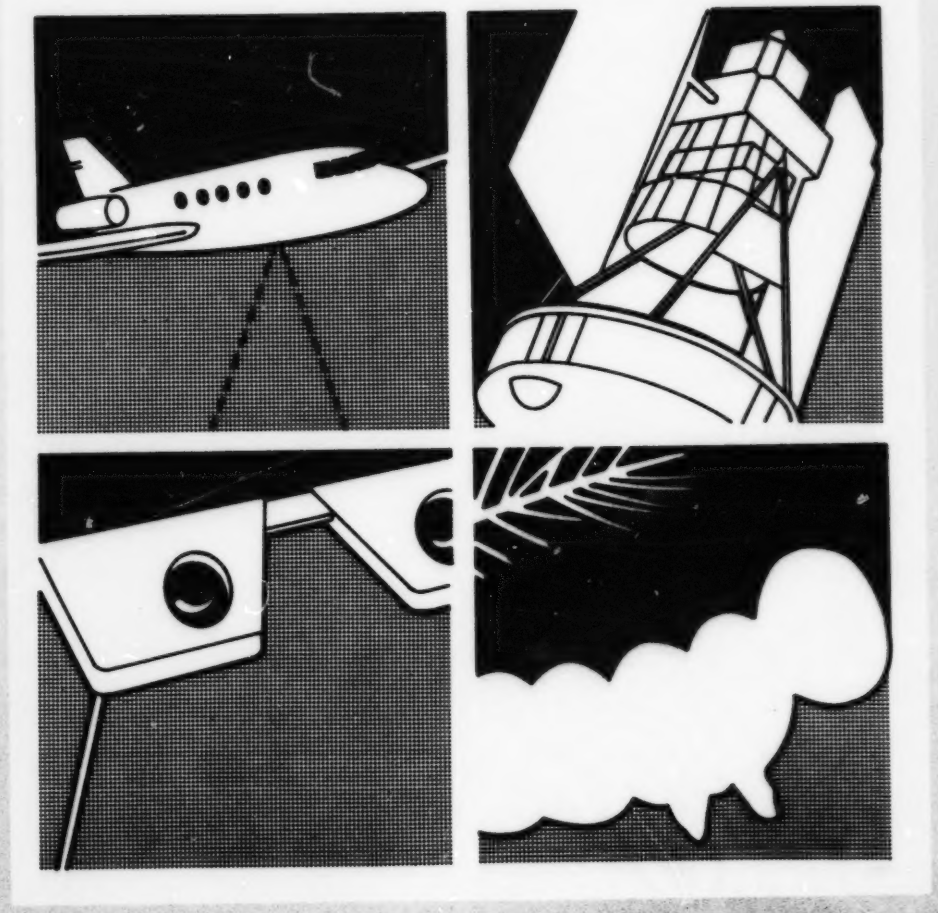
Pacific [illegible]st Research Centre



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Remote Sensing in Forest Damage Detection and Appraisal — Selected Annotated Bibliography

Philip Gimbarzevsky

Environment Canada
Canadian Forestry Service
Pacific Forest Research Centre

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Abstract

This report is the result of a survey of technical literature dealing with the application of remote sensing technology for the detection and appraisal of forest damage. The selected titles (primarily covering the years 1969-1983) are classified by damage types, sensors, and geographic areas, annotated, and arranged in an alpha-numerical order by senior authors. A list of references on remote sensing bibliographies, manuals and textbooks, and an index to damage types are provided.

Résumé

L'auteur présente les résultats d'une étude des publications techniques portant sur l'application des techniques de télédétection à l'évaluation des dommages forestiers. Les titres retenus (couvrant principalement les années 1969 à 1983) sont classés en fonction des types de dommages, des détecteurs et des régions géographiques; ils sont annotés et présentés suivant un ordre alphanumérique d'après l'auteur principal. Une liste de références couvrant les bibliographies, ouvrages et manuels sur la télédétection, ainsi qu'un index pour les types de dommages sont fournis.

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Introduction

The earliest records on the application of remote sensing for the assessment of forest damage in Canada are two short papers published in 1920 in the Canadian Forestry magazine: *Flying studies of forest and insect damage* (pp. 467-468) believed to have been written by Ellwood Wilson, and *An aerial survey of forests in Northern Ontario* (pp. 516-518), by R.D. Craig.

The author of the first paper was then the Chief Forester of the Laurentian Paper Company. In 1919, he arranged, through the St. Maurice Protective Association a loan of two Curtiss HS-2L Flying Boats to assess their usefulness for forest fire patrols and to check the spread of spruce budworm infestations. While sketching the infestation boundaries during the flight, Wilson also used a hand-held camera. After seeing the wealth of information contained on aerial photographs he became an enthusiastic promoter of aerial survey techniques.

The first annotated bibliography on remote sensing in forest damage was published in 1969 by the Forest Management Institute (Murtha, P.A. *Aerial photographic interpretation of forest damage: An annotated bibliography* , Forest Management Institute, Ottawa, Ontario, Information Report FMR-X-16, Forestry Branch Department of Fisheries and Forestry, March 1969). Since 1969, the use of remote sensing in forest surveys, and particularly in the assessment of forest damage, has greatly increased. As the amount of technical literature on the improved techniques or new sensors has more than doubled during the past decade, there existed a need to compile an updated list of titles on forest damage; such was the objective of this report.

To provide a cross-section of damage detection and appraisal topics, a total of 187 titles were selected (from some 480 reviewed) covering mainly case studies, various types of damage, or practical applications of specific sensors. Basis for exclusion was the date of publication (167 titles were pre-1969), and a direct relevance to forest damage. All titles are numbered and listed by authors in alphabetical order. The type of damage, sensor and geographic area are included with most annotations. An index to damage types and additional references on remote sensing bibliographies are also provided.

Over 40% of annotated titles are on the damage by insects, 20% on plant diseases, 19% on the biological stress, or general tree mortality, 9% on damage by toxic chemicals or fumes, 7% on damage caused by fire, wind, flooding and soil erosion, and 3% on damage by man and other disturbances.

Aerial photography, mainly color and color-infrared, has been the most frequently used sensor (over 75% of publications); the multispectral scanner (MSS) imagery, satellite and airborne, in 15%; thermal IR sensors are used in 6%, and other sensors are used in 4% of publications. In many cases, aerial photography was used in addition to other sensors.

About one-third of the described work was done in Canada, 55% in the United States, 5% in Europe and 7% in other countries (Australia, New Zealand, India, USSR). Over one-half of the Canadian publications (51%) refer to the Ontario-Quebec-Atlantic Region, 12% to the Prairie Provinces, and 37% to British Columbia.

Remote sensing literature for the review period reflects the advances both in the development of sensor systems and in improved capabilities for the analysis of remote sensing data. These new sensor systems and the elaborate techniques of computer-assisted analysis are promising, but relatively expensive. Often, the desired information could be derived more efficiently through a simple and more readily available approach.

1. Abrahamson Lawrence P., P.F. Hopkins, W.L. Johnson, 1979

Detection and classification of Scleroderris canker in pine stands using aerial photography

State University of New York, College of Environmental Science and Forestry, Syracuse, N.Y. 13210. 71 pp.

Damage: Scleroderris canker
Sensor: Color and Color-IR 70-mm aerial photography.
Area: Northeast of Syracuse, N.Y., U.S.A.

Eight study plots (about 1 a. each) of known infection levels have been interpreted on aerial 70-mm normal color and color-IR transparencies. The researchers defined five infection levels, the identifying characteristics of Scleroderris canker, and the relationships between these identifying characteristics and the level of infection of the stand. Photointerpretation keys were developed from these relationships and were evaluated on aerial photography of thirteen test plots by personnel likely to use the keys in actual practice.

Scleroderris canker was detectable and classifiable to an acceptable degree of accuracy on aerial photographs. Photographs taken in June or July on color-IR film at medium scale (approximately 1:12 000) are best for the survey of the disease. Stereoscopic viewing of the photographs with a good magnifying stereoscope is probably the best interpretation technique. When using 70-mm photography, the best technique is to use a good hand-held lens stereoscope with at least 4 X magnification on slightly larger scale photographs (approximately 1:10 000). Photointerpretation can improve the present ground survey techniques by helping to make more efficient use of field personnel and time.

2. Aldrich, Robert C. 1975

Detecting disturbances in a forest environment

Photogramm. Eng. Remote Sens. 41:39-48

Damage: Disturbances in forest environment
Sensors: High altitude color-IR photography and space imagery
Area: Nine counties in Georgia (west of Atlanta)

This paper reports preliminary investigations using 1:20 000 scale color IR photography and satellite MSS imagery for detection of major changes in forest and non-forest land-use categories (harvesting, silvicultural treatments, land clearing, insect and disease, wildfire, flooding, regeneration and other). Late fall to late spring imagery is the best period of the year for detecting forest disturbances.

3. Aldrich, R.C. and R.C. Heller, 1969

Large-scale color photography reflects changes in a forest community during a spruce budworm epidemic

Proceedings of a Symposium on Remote Sensing in Ecology. 1968, June 19. Madison, Wisconsin. Philip L. Johnson *Ed.* University of Georgia Press, Athens. p. 30-45.

Damage: Spruce budworm
Sensor: Large scale color photograhs
Area: Northeastern Minnesota, USA

Nine 1-acre (0.4-ha) plots in spruce-fir stands were photographed annually during a 10-year period with large scale (1:1980 and 1:1584) color film for the development of techniques to assess damage by spruce budworm. Damage to spruce-fir stands was assessed on the photographs and related to budworm populations and damage measured on the ground. The color photography provided a good assessment of changes in balsam fir density following an epidemic, and permitted mapping differences in species frequency, compostion and crown cover.

4. Alger, Larry A., P.J. Egan and H.J. Heikkenen, 1978

Previsual detection of stressed loblolly pine (*Pinus taeda* L.)

Proceedings of the symposium on Remote Sensing for Vegetation Damage Assessment. 1978, February 14-16. Seattle, Washington, American Society of Photogrammetry. pp. 65-72.

Damage: Stress
Sensor: Thermovision system
Area: Virginia, USA

This paper describes the use of an AGA Thermovision system 680 for a previsual detection of relative, apparent temperature differences between stressed and healthy loblolly pines (*Pinus taeda* L.). Apparent temperatures of stressed foliage were from 0.5° to 2°C warmer than healthy foliage.

5. Antrop, M. and L. Daels. 1978

Determination of geographical surfaces caused by vegetation
damage

Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment. G. Hildebrandt and H.J. Boehnel *Eds.* 1978, July 2-8. Freiburg, Federal Republic of Germany. International Archives of Photogrammetry. 22: 2095-2103.

Damage: Various types
Sensor: Color-IR aerial photography (1:8000 and 1:40 000)
Area: N/A

Paper describes a new methodology of damage assessment which integrates geographical and plot interpretation techniques. The trees are used as an indicator and damage area is detected as a relative color difference. In addition to tone, the shape, size and density of the tree is analyzed stereoscopically and damage causes are grouped into seven classes: insect, soil deterioration, chemical soil pollution, water deficiency, atmospheric, chemical pollution and bad maintenance. The method consists of four steps: detection on aerial photographs, quantification by grid cells, transformation into a geographical surface, and interpretation of terrain patterns.

6. Ashley, M.D., J. Rea and L. Wright, 1976

Spruce budworm damage evaluation using aerial photography

Photogramm. Eng. Remote Sens. 42:1265-1272

Damage: Spruce budworm
Sensor: 70-mm color and color-IR
Area: Mixed stands in Maine, U.S.A.

Color and color-IR imagery taken at several times of the year, and interpreted by using several viewing methods, were evaluated for identification of new infestations, tree mortality and stands requiring spraying. Summer color photography was best for interpreting current moderate or heavy budworm feeding. Early summer and fall photography was most suitable for evaluating past feeding and overall tree condition. Mortality was best identified on early summer or fall color-IR imagery. Scale and viewing method greatly influenced interpretation accuracy. Individual tree detail could be observed at scales 1:9900 and larger. Tree and stand condition were most accurately interpreted by using a 7X monocular viewer on the backlighted outer portions of the frame. Mortality counts were equally accurate using 2X, 4X or 7X stereoscopic and 7X monoscoptic viewing at the scales 1:31 680 and larger.

7. Backman, Bob, Tim Gregg and Rick Johnsey, 1978

Washington State Forest Insect Survey-Combining aerial sketch map and remote sensing techniques

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp 455-463.

Damage: Insects
Sensor: Aerial sketch mapping
Area: Washington State, USA

The forest insect survey described in this paper is based on aerial sketch mapping and classification of observed damage caused by defoliating and sucking insects into three severity classes (light, moderate and heavy). Bark beetle damage is recorded as the number of dead trees in a group, or per acre. The future use of aerial photography is considered. It will include the orthophoto maps to replace present 1:125 000 scale planimet-

ric maps, construction of photographic keys illustrating damage severity classes and the use of aerial camera in areas that are difficult to accurately sketch.

8. Beaubien, J. and L. Jobin, 1974

Forest insect damage and cover types from high altitude color-IR photographs and ERTS-1 imagery

Proceedings of the Symposium on Remote Sensing and Photo Interpretation. 1974, October 7-11. Banff, Alberta, Canada. Canadian Institute of Surveying. pp. 449-454.

Damage: Eastern hemlock looper
Sensor: Small scale color-IR photography and ERTS-1 imagery
Area: Anticosti Island, Quebec

Defoliation and mortality of balsam fir stands caused by eastern hemlock looper was assessed from 1:70 000 scale color-IR photography and satellite imagery. The color-IR transparencies were viewed with a mirror stereoscope and damaged areas were stratified into 25% mortality classes. A visual analysis of ERTS-1 winter imagery provided adequate tonal contrast for delineation of two levels of tree mortality (50% and 75%).

9. Beaubien, J. and L. Jobin, 1974

ERTS-1 imagery for broad mapping of forest damage and cover types of Anticosti Island

Can. Surveyor 28:164-166.

Damage: Eastern hemlock looper
Sensor: Color-IR 1:70 000 photography and ERTS imagery
Area: Anticosti Island, Quebec

The authors describe the production of a general map of Anticosti Island from selected frames of ERTS imagery showing distribution of forest types and areas damaged by the hemlock looper. The ground truth data were obtained from 1:70 000 scale color-IR photographs.

10. Bell, J.C. Jr. 1972

Forest insect surveys using color infrared photography

Proceedings of the Annual Meeting of the American Society of Photogrammetry. 1972. pp. 332-336

Damage: Southern pine bark beetle
Sensor: Cartographic camera with 12" lens, scale 1:6 000
Area: Southeastern United States

The application of color-IR photography to evaluate insect damage in southeastern U.S. are described in general terms; the work includes the following steps: map preparation, film, filters and equipment check list, aerial photography, film processing, plotting, interpretation of 200 photo sample plots, field checking, data analysis and reporting.

Survey cost depends on survey intensity (from 2% to 50%) and the size of area surveyed. The cost in 1972 for an 11% intensity over a 300 000 acre area is about 0.7¢ per acre.

11. Benson, M.L. and B.J. Myers, 1978

Aerial assessment of dieback of Norfolk Island pine (*Araucaria heterophylla*) in its natural environment

Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment. G. Hildebrandt and H.J. Boehnel *Eds.* 1978, July 2-8. Freiburg, Federal Republic of Germany. International Archives of Photogrammetry. 22: 2013-2026.

Damage: Pine dieback due to ecological disturbance.
Sensor: Color-IR photography
Area: Norfolk Island, South Pacific

Color-IR large scale aerial photography and supplementary oblique photography was used to map the dieback damage of Norfolk Island pine (*Aracaria heterophylla*) in its natural environment.

The study indicates that the main cause of damage was severe ecological disturbance due to overgrazing and trampling by stock, nutrient depletion on colonized farmland, and severe competition from imported grasses and shrubs.

12. Blazquez, C.H. 1971

Detection of foliar diseases of vegetable crops with infrared color photography

Proceedings of the Third Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1971, March 2-4. University of Florida, Gainesville, Florida. Abraham Anson *Ed.* American Society of Photogrammetry. pp. 236-245.

Damage: Foliar diseases
Sensor: Color-IR aerial photography
Area: Florida, USA

True color and color-IR aerial photography (various scales) was used for the detection of most common foliar disease in vegetable crops. The greatest discrimination between healthy and diseased plants was obtained with fields infected with late blight of tomatoes, downy mildew of cucumbers and mosaic of watermelons.

13. Blazquez, C.H., G.J. Edwards and F.W. Horn, 1979

Aerial photographic surveillance of tree health in a citrus grove

Proceedings of the Seventh Biennial Workshop on Aerial Color Photography in the Plant Sciences and Related Fields. 1979, May 15-17. University of California, Davis, California. American Society of Photogrammetry. pp. 209-220.

Damage: Stress - citrus trees
Sensor: Color-IR
Area: Polk County, Florida, USA

Sequential color-IR aerial photography flown during winter, spring and summer was used for the detection of stressed citrus trees. The spring season flights gave the best separation between healthy and stressed trees. The best scale for photo interpreations was 1:3960 taken with a 305-mm lens, which was much superior to the same scale photography taken with 152-mm lens.

14. Blazquez, C.H. and F.W. Horn, Jr. 1981

Detection and damage assessment of citrus tree losses with aerial color-infrared photography (ACIR)

Proceedings of the Eighth Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1981, April 21-23. Luray, Virginia. American Society of Photogrammetry. pp. 115-126.

Damage: Citrus tree losses
Sensor: Color-IR film
Area: Florida, USA

Large scale (1:4000) sequential color-IR photography flown with a 12" lens Zeiss RMK-A camera during the winter, spring and summer seasons was used for the development of damage assessment system of citrus tree losses. Spring photography showed the greatest differences between healthy and diseased trees and had the least shadow and background interference for photo interpretation. Trees showing slight damage were detected on Color-IR photographs before they were identified in ground surveys.

15. Bird, T., B.J. Myers and D.A. Ratkowsky, 1978

Theory of vegetation damage: recognition of patterns of disease in tall forests

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 253-266.

Damage: Regrowth dieback
Sensor: Color 70-mm aerial phtographs
Area: Australia

This paper describes a "cheap and effective" use of color 70-mm aerial photographs of scales

1:2500 to 1:8000 for the identification of patterns of forest decline in Australia. Photographs of several different disorders were interpreted: dieback in southern regrowth forest in Tasmania, "Brown topping" in *Pinus radiata* plantations, crown scorch in eucalypt forest, insect defoliation in eucalypts, jarrah dieback in tropical rainforests.

16. Brach, E.J., and A.R. Mack. 1972

Difference in reflectance properties of diseased plants grown under different environments

Proceedings of the First Canadian Symposium on Remote Sensing. 1972, February. Ottawa, Ontario. Dennis White *Ed.* Canada Centre for Remote Sensing, Department of Energy, Mines and Resources, Ottawa. pp. 103-107.

Damage: Diseased plants
Sensor: Spectrometers and multi-spectral photography
Area: Ontario

This paper describes the use of field and laboratory spectrometers supplemented by multispectral photography to record changes in reflectance from leaf surfaces affected by disease, fertilization, maturation and changes in soil temperature and moisture conditions.

17. Bradshaw, F.J. 1974

Large scale 70 mm colour photography as an aid to detecting jarrah dieback

Proceedings of the Symposium on Remote Sensing and Photo Interpretation. 1974, October 7-11. Banff, Alberta, Canada. Canadian Institute of Surveying. pp. 439-448.

Damage: Dieback
Sensor: 70-mm color-IR photography
Area: Western Australia

Describes and evaluates a two-stage interpretation system for the detection of dieback caused by *Phytophtora cinnamonii* Rands in Jarrah (*Eucalyptus marginata* Sm) forest in western Australia. The 670 km² test area was viewed on 1:3000 scale color IR sample strips under 2X and 5X stereoscopic magnification, and stratified into four damage intensity classes. The type boundaries were plotted on the 1:40 000 scale photo coverage and the interpretation extended by using existing distinguishing features. The field transect mapping along the 70-mm strips and in the area covered by 1:40 000 photography provided ground data for the comparison of photo interpretation results. The sources of infection and the boundaries of incipient dieback were detected with a high degree of reliability (84%-98%) on 1:3000 scale color-IR photographs.

18. Bradshaw, F.J. and R.J. Chandler, 1978

Full coverage at large scale: Large scale undercloud 70 mm colour aerial photography for detecting and mapping a disease in the forest understorey over extensive areas

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 267-290.

Damage: Jarrah dieback (*Phytophtora cinnamomi* Rand.)
Sensor: Color 70-mm film 1:4000
Area: Western Australia

Large scale (1:3000-1:5000) 70-mm color aerial photograhy flown under clouds with a Vinten 50-mm camera was used for interpretation and mapping the *Phytopthora cinnamomi* infestations over an extensive area. This paper describes the photographic system, navigation, acquisition of complete photo coverage, detection and interpretation of 70-mm transparencies, field checks and mapping. Actual cost of the survey (about 60¢ per ha) includes: aircraft rental: (20¢ per ha), film and processing (15¢ per ha), interpretation, field checking, and mapping: (25¢ per ha).

19. Brown, H. Daniel, 1971

Declining loblolly pine not reliably detected with aerial color film

Proceedings of the Third Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1971, March 2-4. University of Florida, Gainesville, Florida. Abraham Anson *Ed.* American Society of Photogrammetry. pp. 246-254.

Damage: Decline in growth of loblolly pine
Sensor: Normal color and color-IR films
Area: West Gulf Coastal plain in Louisiana, USA

Seven circular plots with 20 trees per plot were analyzed on true color and color-IR aerial photography taken in February and May at the scales of 1:2000 and 1:4000 to detect a potentially serious decline in loblolly pine stands. The decline could not be reliably detected with the methods employed.

20. Buchman, N., and R.C. Hall, 1975

Comparison of digital and visual evaluation of LANDSAT-1 imagery for detection and monitoring of forest insect infestations

Proceedings of the Workshop for Environmental Applications of Multispectral Imagery. 1975, November 11-13. Fort Belvoir, Virginia. U.S. Army Topographic Laboratory. p. 34-37.

Damage: Mountain pine beetle and lodgepole pine needle miner
Sensor: MSS Landsat Imagery
Area: Sierra Nevada, California

Digital and visual interpretation methods were employed for the assessment of pine beetle and lodgepole needle miner infestations from Landsat imagery. The machine-assisted analysis of digital tapes achieved classification of light and heavily damaged forest stands, and non-host mixed conifers, mountain meadows, rock domes, glaciers and lakes. The results were comparable to the visual interpretation of Landsat color composites enlarged to a scale of 1:80 000. Digital classification required less time and less underflight support than visual classification, and provided greater spatial discrimination. Visual interpretation of enhanced color composite enlargements permitted detection of heavy, medium and light defoliation classes, and heavy mortality class with a reasonably high degree of reliability.

21. Cagirici, M. and G. Hildebrandt. 1978

Die Beobachtung der Entwicklung von chronischen Wald-Schaden durch Interpretation von IR-Farbluftbildern

Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment. G. Hildebrandt and H.J. Boehnel *Eds.* 1978, July 2-8. Freiburg, Federal Republic of Germany. International Archives of Photogrammetry. 22: 2045-2057.

Damage: Sulfur dioxide emission
Sensor: Color-IR aerial photography (1:5000)
Area: Pine forest in W. Germany

Sequential color-IR aerial photographs taken at 1-, 2- and 3-year intervals were used to determine the state of health of pine forest subjected to sulfur dioxide fumes. Stereoscopic interpretation involved the recognition of live, slightly affected and dying or dead pine trees.

22. Caylor, J., J. Pierce and W. Salazar, 1982

Optical bar panoramic photography for planning timber salvage in drought-stressed forests

Photogramm. Eng. Remote Sens. 48:749-653.

Damage: Drought and bark beetles
Sensor: Color-IR and optical bar panoramic camera
Area: Northern California, USA (about 150 000 km²)

Color-IR panoramic transparencies were used to map tree mortality caused by bark beetles for planning salvage operations. Authors describe the photo mission, preparation of panoramic photography for field use, steroscopic viewing and delineation of infested areas. Late fall flights were found to be preferable to summer flights.

23. Chaturvedi, Abinash Chandra, 1978

Vegetation damage surveying in India

Proceedings of the Symposium on Remote Sens-

ing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 439-454.

Damage: General
Sensor: Aerial photography, LANDSAT
Area: Sunderban region, India

Recent application of remote sensing in India for a long range planning of the use of water is described. Flood control, irrigation needs, pollution and associated damage to the vegetation are included.

24. Ciesla, W.M. 1974

Forest insect damage from high-altitude color-IR photos

Photogramm Eng. 40: 683-689

Damage: Mountain pine beetle, Pine butterfly and Western spruce budworm
Sensor: Wild RC10, 6" lens, U-2 Color-IR photography, scale 1:126 720
Area: Western Montana, USA

Ultra-small-scale (1:126 000) color-IR aerial photographs were examined under a Bausch and Lomb zoom stereoscope. Color patterns on photographs were used for determination of damaged trees. Bark beetle attacked trees register as beige or yellow and defoliated trees register as grey or grey-green.

The study shows that the ultra-small scale color-IR photography also has a potential use in detection and mapping of total defoliation caused by pine butterfly, provided it is restricted to pure stands. The mapping of stands having heavy tree mortality due to bark beetle infestations was only partially successful, while the current year's defoliation caused by western spruce budworm was not detected.

25. Ciesla, William 1977

Color vs. color-IR photos for forest insect surveys

Proceedings of the Sixth Biennial Workshop on Aerial Color Photography in the Plant Sciences and Related Fields. 1977, August 9-11. Fort Collins, Colorado. American Society of Photogrammetry. pp. 31-42.

Damage: General — Current mortality and defoliation
Sensor: Color and Color-IR photography
Area: N/A

This paper describes available color and color-IR films and their use in interpretation of current mortality and foliar injury. The nature of damage, atmospheric haze, major forest types differentiation, the presence of seasonal foliage coloring, etc. must be considered in the selection of a proper film.

26. Ciesla, W.M. 1980

Operational remote sensing for forest insect and disease management - some challenges and opportunities

Proceedings of the Symposium on Remote Sensing for Natural Resources. 1979, Sept. 10-14. University of Idaho, Moscow, Idaho. University of Idaho. pp. 39-47.

Damage: Forest insects and diseases
Sensor: Photographic and other
Area: N/A

This paper provides a review of current applications of photographic and non-photographic sensors for data collection in forest pest management. The author discusses the transfer of new technology into operational use as well as related user-defined needs, dynamic characteristics of forest insects and disease outbreaks necessitating rigid scheduling of data collection, and specialized training and commitment of forest insect and disease management specialists.

27. Ciesla, W.M. 1981

Development and application of panoramic aerial photography in forest pest management

Proceedings of the Eighth Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1981, April 21-23. Luray, Virginia. American Society of Photogrammetry. pp. 19-28.

Damage: Mountain pine beetle
Sensor: Panoramic color-IR aerial photography
Area: Pine forests in Western United States

Recent applications of panoramic aerial photography for estimating losses caused by the mountain pine beetle and planning salvage of insect killed timber are described. The advantage of the optical bar panoramic camera system is in rapid acquisition of high-resolution photography of large areas. Disadvantages include a relatively high acquisition cost, unconventional film size and a changing scale of photography.

28. Ciesla, W.M., R.A. Allison, and F.P. Weber, 1982

Panoramic Aerial Photography in Forest Pest Management

Photogramm. Eng. Remote Sens. 48: 719-723.

Damage: Forest pests - general
Sensor: Optical bar (Itek KA-80A) camera
Area: N/A

This paper describes the Itek KA-80A Optical Bar aerial camera and its use for a rapid data acquisition over large areas of forest land. The KA-80A is equipped with a 24" (609.6 mm) focal length lens that produces a panoramic image 127 cm long and 11 cm wide. From a height of 60,000 feet (18 300 m) the scale at nadir is 1:30 000 and 1:60 000 at 60° from nadir. A single frame provides a forward ground coverage of 2.3 nautical miles (4.25 km) at nadir and 17.1 nautical miles (31.6 km) at 60 degrees of nadir. Among the advantages of panoramic photography is the combination of high image resolution and large area coverage, which permits a rapid stratification of outbreak areas and a detailed crown count. Disadvantages include the unusual film format (4 1/2" x 50"), continuously changing photo scale, the requirements for a high-altitude aircraft, and the high cost in comparison with conventional photography.

29. Ciesla, W.M. and R.E. Acciavatti, 1982

Panoramic aerial photography for mapping Gypsy moth defoliation

United States Forest Service Forest Pest Management Methods Application Group, Fort Collins, Colorado 80526, USA.

Damage: Gypsy moth defoliation
Sensor: Color IR film in the ITEK IRIS-II Panoramic camera.
Area: Central Pennsylvania.

A 7000 km² area of mixed hardwood was photographed with a "third generation" panoramic camera system and color-IR film using a U-2 aircraft at 19800 m ASL. The 1:31 000 scale color transparencies were viewed monoscopically on a portable light table. Areas of defoliation were sketchmapped as polygons of defoliation on 1:24 000 scale maps and classified as moderate (30-60% defoliation) or heavy and widespread (60% defoliation). The results compared with aerial sketch mapping showed 55.1% agreement over the entire test site. The cost of panoramic photography was 1.7 times that of aerial sketch mapping, but only 1/3 the cost of conventional aerial photography. Authors state that "panoramic aerial photography is a cost effective alternative for data acquisition."

30. Ciesla, W.M., L.E. Drake and D.H. Wilmore, 1971

Color photos, aerial sprays and the forest tent caterpillar

Photogramm. Eng. 37: 867-873.

Damage: Defoliation by tent caterpillar
Sensor: Color and color-IR photography
Area: Test site in Mobile and Baldwin Counties, Alabama

Color and color-IR 1:6000 and 1:1 5000 scale aerial photographs were used to measure the amount of foliage saved by aerial application of experimental chemicals to suppress infestations of the tent caterpillar. Plots protected by aerial sprays were readily discerned on both films, but IR provided greater contrast between susceptible and non-susceptible host types and between

classes of defoliation. The 1:15 000 scale was somewhat superior because it permitted analysis of larger area and measurement of the impact of spray drift upon adjacent plots.

31. Ciesla, William M. and William H. Klein. 1978

Inventory of bark beetle mortality in coniferous forests with color and color-IR photography

Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment. G. Hildebrandt and H.J. Boehnel *Eds.* 1978, July 2-8. Freiburg, Federal Republic of Germany. International Archives of Photogrammetry. 22: 2001-2011.

Damage: Bark beetle
Sensor: Color IR, Color and Pan film with A-25 filter (scale (1:30,000-1-60,000) and KA80A optical bar and HR 732 9" x 18" frame camera.
Area: Northern Idaho, Central Oregon and California

High altitude color and color-IR aerial photography obtained with the KA80A optical bar panoramic and an HR 732 9" x 18" frame camera were used for stratification of pine beetle infestation intensity. Damage intensity classes were classified by grid cell using a microfiche viewer with 13X magnification, to be compared to counts on corresponding 1:6000 scale conventional color-IR photography and ground truth acquired on a number of 40-acre cells. Only preliminary results are available, which "appear promising, and if successful will provide the basis for substituting aerial sketch mapping with small scale, high resolution photography".

32. Clerke, William H. and Richard O. Mahan, 1978

The application of digital terrain model and space resection techniques to digitizing the position of southern pine beetle infestations delineated on large scale aerial photographs

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 161-179.

Damage: Southern pine beetle
Sensor: N/A
Area: N/A

This paper describes the use of Forest Service Digital Terrain Information System for determining the position and area of delineated features and plotting these features in map or aerial photographic perspective. The system utilizes a digital terrain model in conjunction with space resection to determine the ground coordinate location of areas delineated on aerial photographs. The study site involved some 35 000 ha of mountainous terrain in Georgia. Groups of red and fading trees affected by southern pine beetle were digitized for entry into the system along with control data required for resection of the photography.

33. Cochrane G.R. 1968

False color film fails in practice

Photogramm. Eng. 34: 1142-1146

Damage: Insects and disease - general
Sensor: Color-IR film
Area: N/A

This is a discussion paper refuting statements made by the Australian forestry workers that false-color film is "less suitable for disease and insect damage detection studies than true-color film". They assume that absence of chlorophyll should register as blue-green on IR film. Published work and preliminary studies show that absence of chlorophyll does not necessarily imply blue-green color. Spectral reflectance in the infrared region is affected by physical and physiological properties of leaves. A desired color shift in sclerophyll vegetation is noted by the use of color compensating filters.

34. Daels, L. and M. Antrop 1978.

The use of a temporal analysis of C.I.R. images for the evaulation of the vegetation damage in industrial areas

Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment. G. Hildebrandt and H.J. Boehnel *Eds.* 1978, July 2-8. Freiburg, Federal Republic of Germany. International Archives of Photogrammetry. 22: 2083-2094.

Damage: General environmental conditions
Sensor: Color-IR photography
Area: No specific area

This paper discusses in general terms the application of color-IR imagery for detection of stress or damage by vegetation. The authors suggest the use of trees as indicators for the monitoring of the environmental quality control. The concluding statements emphasize the following:

1) the color of damaged trees on color-IR photographs should always be considered as a relative color difference with respect to the healthy trees;

2) Densitometric measurements do not increase the accuracy, rather they induce more interpretation errors.

3) The interpreter should consider the color and whole aspect of the tree, as well as its situation in the environment.

4) The interpreter should keep in mind the infuence of radial displacement, topography, illumination conditions and background radiation.

5) Stereovision should always be used.

6) The evaulation of the reasons of damage should never be made upon single trees or on small groups, but relations should be inferred from spatial *patterns* of damaged trees and from other associated environmental phenomena.

7) In order to influence the different registration conditions, scales should not be too large; optical magnification is preferred.

35. Dickison, R.B.B. and D.O. Greenbank, 1972

The spruce budworm problem and topographic variation of forest canopy radiation temperatures

Proceedings of the First Canadian Symposium on Remote Sensing. 1972, February. Ottawa, Ontario. Dennis White *Ed.* Canada Centre for Remote Sensing, Department of Energy, Mines and Resources, Ottawa, pp. 111-119.

Damage: Spruce budworm
Sensor: Radiation thermometer and IR thermal scanner
Area: New Brunswick

A radiation thermometer with a thermal IR scanner was flown 300-400 m above the ground to develop a local climate map and to identify areas most favourable for the spruce budworm. Six flights were made between 07:00 in the morning and 16:30 in the afternoon. The greatest variations of temperature occurred during the noon flight, but the influence of slope and aspect produced temperature differences of less than 3°C between north and south facing slopes.

36. Dillman, R.D., 1982

Estimating mountain pine beetle-killed ponderosa pine over the front range of Colorado with high altitude panoramic photography

Photogramm. Eng. Remote Sensing. 48: 741-747.

Damage: Mountain pine beetle
Sensor: Color IR panoramic photography
Area: Colorado Forest Range, Colorado

Color-IR panoramic transparencies were used for the assessment of mountain pine beetle damage over an extensive (21 000 km²) forested area in Colorado. The survey was based on a three-stage sampling scheme with the selection probability proportional to size at each stage. The photographs were analyzed monoscopically and the number of faders was counted and recorded by sampling units, and correlated with the ground counts. The relative standard error of the survey was 13.8%.

37. Dillman, R.D., B.C. Eav and J.C. Prill. 1979

Evaluation of high altitude imagery for assessment of mountain pine beetle

Proceedings of the Seventh Biennial Workshop on Aerial Color Photography in the Plant Sciences and Related Fields. 1979, May 15-17. University of California, Davis, California. American Society of Photogrammetry. pp. 165-177.

Damage: Mountain pine beetle
Sensor: Color-IR, Color and Panchormatic aerial photography
Area: Sierra Nevada, California, USA

Three types of aerial photography (Color, Color-IR and black-and-white) taken with two camera systems (Itek KA-80A panoramic optical bar, and ACTRON HR-732 9x18: frame cameras) were evaluated to determine their effectiveness for assessment of mountain pine beetle damage. Six photo interpreters were used to count faded trees in 16-ha ground plots on three film types at the small scale (1:30 000) and correlated with 1:7000 color-IR obtained with a Zeiss RMK camera. The results revealed the following:

- Color-IR film resulted in the most consistently high correlation coefficients
- Imagery obtained with HR-732 large format camera had higher correlation than the panoramic (optical bar) camera
- Stereoscopic viewing provided higher correlation than monoscopic viewing
- Experienced interpreters were less affected by camera system, film types or viewing mode than inexperienced interpreters

38. Dillman, R.D., S.S. Shen, B.B. Eav, and W.B. White. 1981

Operational test of panoramic aerial photography for estimating annual mortality of ponderosa pine caused by mountain bark beetle

Nationwide Forestry Application Program. United States Forest Service, Houston, Texas. 22 p + appendix.

Damage: Mountain pine beetle
Sensor: Color-IR panoramic photography
Area: Colorado Forest Range, Colorado, USA

This technical report describes and illustrates the procedures used in the appraisal of mountain pine beetle damage based on interpretation of 1:30 000 scale color-IR panoramic aerial photography. A three-stage sampling method with selection according to probability proportional to size was used. Information from each stage was combined to estimate the number of trees killed and associated volume loss. In the 7 500 km² study area an estimated 79 898 trees with a volume of 950 199 cubic feet were killed in 1980.

39. Dillman, R.D. and W.B. White, 1982

Photointerpretation Guide for identifying pines killed by the mountain pine beetle

National Forest System, State and Private Forestry. U.S. For. Serv. Report NFAP-267, Washington, D.C. 35 p + Appendix

Damage: Mountain pine beetle
Sensor: Color and color-IR high altitude aerial photography
Area: Colorado, Montana and Wyoming, USA

This is a comprehensive description of the high altitude panoramic photography system and application of color-IR photography in photo interpretation of ponderosa and lodgepole pine, primary host species for mountain pine beetle. Selected examples (24 plus 15 in Appendix) were intended to illustrate the procedures, but the black-and-white reproductions of color IR stereograms are very poor and useless for the intended purpose.

40. Dottavio, Lisette C., and Darrel L. Williams, 1983

Satellite technology: an improved means for monitoring forest insect defoliation

J. For. 81:30-34

Damage: Defoliation by Gypsy Moth
Sensor: LANDSAT MSS and high altitude air photographs
Area: Hardwood forests in Pennsylvania, USA

A computer-aided analysis of multi-date Landsat MSS imagery was used for discrimination of heavily defoliated hardwood forests from nondefoliated forests. A vegetation index technique, based on the ratio of the IR (MSS band 7) to red (MSS Band 5) response (Vegetation Ratio Index or VRI), was applied to create a new "Assessment Image", showing nondefoliated, moderately defoliated and heavily defoliated forests. When this assessment image was compared with actual ground conditions, the accuracy of Landsat derived classification was 88.5% correct for heavy defoliation, 64% for moderate defoliation and 56.6% for healthy forest.

41. Eav B.B., R.D. Dillman, J.C. Prill and R.E. Hinkle, 1980

Mountain pine beetle damage surveys with high altitude panoramic photography

Technical Papers of the Fall Technical Meeting. 1980, October 7-10. Niagara Falls, New York. American Society of Photogrammetry. pp. DA-1-D-1 to DA-1-D-14

Damage: Mountain pine beetle
Sensor: Optical Bar Panoramic Camera, Color-IR film, U-2 aircraft.
Area: South Dakota and Colorado, U.S.A. (about 27 000 km²)

Optical Bar Panoramic Camera (Itek KA-80A) with a 24" lens and color-IR film was used for the assessment of mountain pine beetle infestations in two pilot areas - Black Hills National Forest in South Dakota and Colorado Front Range, Colorado. For estimating the total number of faders on the photographs, a two-stage variable probability sampling approach was applied in South Dakota, and a three-stage approach was used in Colorado. In the first stage, the area was subdivided into primary sampling units of 60 — 70 km² each; in the second stage, the primary sampling units were subdivided into 50 — 60 ha secondary sampling units, and in the third stage, these secondary units were subdivided into 1-ha cells. The measurement made on every sampling unit was a quick sample count of the number of faders. Finaliy, the cells or tertiary sampling units were field checked and faded trees were counted and measured. Results indicate that opical bar surveys are a realistic alternative to conventional survey techniques and potentially more cost effective.

42. Edwards, George J., Tom Schehl and E.P. Ducharme, 1975

Multispectral sensing of citrus young tree decline

Photogramm. Eng. Remote Sens. 41: 653-657

Damage: Young Tree Decline
Sensor: 24-channel spectral analyser in C-130 aircraft
Area: Block of Valencia orange trees near Fort Pierce, Florida

The LARS computer program at Purdue University was used to analyse MSS data to identify and map citrus trees affected with young tree decline. The overall accuracy of the method for determining healthy and diseased trees was 89% using data collected at 820 — 880 nm from aircraft at an altitude of 1500 feet.

43. Epstein, Abraham H. 1975

Role of remote sensing in preventing plant disease and world hunger

Proceedings of the Fifth Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1975, August 19-21. EROS Data Center, Sioux Falls, South Dakota. American Society of Photogrammetry. pp. 61-65.

Damage: Plant disease - General
Sensor: Remote Sensing Technology
Area: N/A

The need for development of practical low cost applications of remote sensing technology for monitoring crop damage is discussed. Limiting problem areas discussed are: resolution of

imagery, disease identification, and information dissemination. Immediate needs discussed are: Phytopathologists to be made aware of capabilities of remote sensing technology; more interdisciplinary research; development of remote sensing systems sensitive to spectral signatures of specific plant-pathogen complexes; development of rapid turn-around remote sensing data correlated with ground truth check system; increased plant disease management and control expertise.

44. Fairweather, Stephen E., Merle P. Meyer and David W. French, 1978

The use of CIR aerial photography for Dutch Elm disease detection

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 299-310.

Damage: Dutch Elm disease
Sensor: Color-IR photography
Area: Minneapolis, Minnesota, USA

This paper describes two experimental studies to identify, on 1:9600 and 1:6000 scale color-IR photographs, single trees infested with Dutch elm disease in the urban environment (City of Minneapolis). The results obtained by three photo interpreters are analyzed and compared. Approximately one minute was required to examine one tree on the photographs.

45. Fleming, J. 1978

Exploiting the variability of aerochrome infrared film

Photogramm. Eng. Remote Sens. 44:601-605

Damage: Biological Stress
Sensor: Aerochrome IR
Area: N/A

Among the unique attributes of color-IR film is "IR balance" used in the compilation of histograms illustrating the range of variability. This paper describes the parameters of IR film for high-altitude photography conducted by the Airborne Operations Section of the Canada Centre for Remote Sensing.

46. Fox, Lawrence III. 1978

The effect of canopy composition on the measured and calculated reflectance of conifer forests in Michigan

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp 89-114.

Damage: N/A
Sensor: Spectroradiometer
Area: N/A

Paper describes the use of a Gamma Scientific spectroradiometer installed in a "Hi-Ranger" aerial bucket for a bi-directional measurement of spectral reflectance of conifer forest canopies. The measurements were taken at six narrow wavelength bands selected to locate reflectance minima and maxima and to describe the shapes of spectral reflectance curves in the visible and photo infrared portion of the electromagnetic spectrum. Reflectance measurements were replicated six times for each stand canopy under given canopy conditions and angles of view, zenith and azimuth. A potential use of this research is differentiation between species or for study of forest stands containing live crowns and defoliated branches and boles.

47. Fox III, Lawrence, 1978

Previsual detection: The elusive dream

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 53-64.

Damage: N/A
Sensor: N/A
Area: N/A

Previsual detection is defined as the detection of vegetation damage through remote sensing before a person using their eyes at close range could detect the damage. The controversy concerning previsual detection centered around the sensing of reflected infrared light. The only well documented example of previsual detection is the thermal sensing of plant temperature change associated with water stress. Several examples of early detection of vegetation damage by using both visible and invisible light are discussed. Because color-IR film enhances visible and invisible changes in reflectance, it is recommended that this type of detection no longer be called previsual.

48. French, D.W. 1974

Forest disease detection and control

Remote Sensing Applications to the Management of Agricultural, Forest and Water Resources in Minnesota. Institute of Agriculture Remote Sensing Laboratory Report 74-2. University of Minnesota, St. Paul, Minnesota. pp. 1-12.

Damage: Dutch elm disease and Oak wilt
Sensor: Ektachrome MS and IR
Areas: St. Paul, Minnesota, USA

Various scales (ranging from 1:6000 to 1:31 680) of color and color-IR aerial photography were used for the detection of Dutch elm disease and oak wilt. The author concludes that present techniques are not satisfactory because the detection of Dutch elm disease was only 42% successful. Detection of oak wilt from aerial photographs is feasible, because it "costs no more than ground survey".

49. Gaucher, David, John E. Walker and John R. Schott, 1978

Applications of photometric process in monitoring vegetation damage due to external stresses

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 135-159.

Damage: Defoliation in hardwood forests
Sensor: Color-IR and LANDSAT MSS
Area: Pennsylvania, USA

The authors review some operational methods of vegetation damage assessment and provide important guidance for the use of reflected and emitted energy from vegetation surfaces. They suggest: 1) Avoid using focal plane shutter cameras, 2) Expose sensitometer wedge on the film before processing, and 3) Quantify uncontrollable parameters (atmosteric effect, illumination effect, and subjective judgement). The results of photometric interpretation for the assessment of defoliation from Color-IR photography and MSS Landsat imagery are compared with visual observations. Estimated cost for defoliation mapping using Landsat data is $0.50 per 400 ha compared to $1.25 per 400 ha for aerial sketch mapping.

50. Gimbarzevsky, P. 1970

Air photo analysis of vegetation condition in the vicinity of gas processing plants

Spartan Air Services, Calgary, Alberta. Report Prepared for oil and gas industry, September 1970. 36 p + photomaps.

Damage: Sulphur dioxide
Sensor: Aerial photography
Area: Southern Alberta

This report describes an experimental analysis of medium (1:14000) and large (1:4800) scale panchromatic, color, and color-IR aerial photography for detecting changes in vegetation conditions around two gas processing plants in southwestern Alberta. Four vigour classes were recognized and mapped from color and color-IR photographs. The patches of dead trees were identified on panchormatic photographs, but color and color-IR coverage was much superior for the recognition of scattered trees with a reduced vigour. Medium scale color IR or large scale color photography is recommended for future use.

51. Gimbarzevsky, P. 1982

Application of remote sensing for the appraisal of forest damage. File report on spruce budworm study, Cape Breton Island, N.S.

Pacific Forest Research Centre, Victoria, B.C. 35 p plus appendices (41 color stereograms, Landsat MSS, airborne MSS and vegetation maps produced from MSS digital data).

Damage: Spruce budworm
Sensor: Color-IR photography and MSS imagery
Area: Cape Breton Island, Nova Scotia

This file report describes the spruce budworm damage appraisal study conducted by the Petawawa National Forestry Institute. A stereoscopic analysis of color and color-IR aerial photography is the most reliable tool for the detection and quantification of forest damage. The MSS imagery (Landsat and airborne) did not provide satisfactory results.

52. Gimbarzevsky, P. 1983

Remote sensing of slope failures on the Queen Charlotte Islands

Proceedings of the RNFRF Symposium on the application of Remote Sensing to Resource Management, May 22-27, 1983, Seattle Wash., ASP. 8 pp + illustrations.

Damage: Landslides
Sensor: Small scale black-and-white aerial photography and Landsat MSS.
Area: British Columbia

The use of small scale aerial photography and MSS Landsat imagery for mapping forest damage caused by landslides is described. The work involved a stereoscopic analysis of 1:50 000 scale aerial photographs, stratification of the survey area (9 600 km²) into landscape units, identification of slope failure forms and compilation slope failure frequency maps. Over 8000 debris slides, torrents or avalanches were mapped. With the average size of about 1.65 ha per landslide the estimated denuded area is 13 200 ha, or over 1.3% of the Queen Charlotte Islands land area.

53. Gregg, Tim, Kenelm Russell and Ed Knudson, 1978.

Detection of *Armillaria* root rot damage with shadowless color-infrared photography

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 429-438.

Damage: Root rot (*Armillaria*)
Sensor: Color-IR photography
Area: Washington State, USA

A specialized shadowless color-IR photography, at a scale of 1:6000, was used for mapping *Armillaria* infestations in south-central Washington. Color-IR film exposed with a 300-mm focal lens camera under high overcast was processed to a negative to provide color prints for photo interpretation and field use. Interpretation criteria include canopy structure ("holes"), windthrown trees and tree condition (dead or stressed trees at the infection parameter).

54. Hall, P.M., 1981

Remote Sensing of Douglas-fir trees newly infested by bark beetles

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, The Faculty of Graduate Studies, Dept. of Forestry and Forest Entomology, the University of British Columbia, January, 1981. 68 pp.

Damage: Douglas-fir bark beetle
Sensor: 70-mm color-IR (Vinten 492) scale 1:1100
Area: Tranquille River, B.C. - two plots

Two plots in a newly infested Douglas-fir stand were analyzed on 44 stereo pairs of 70-mm color-IR transparencies and on a MacBeth TR-527 Transmission Reflectance Densitometer using a visual stereoscopic interpretation and density measurements of tree crowns. Significant differences were found between the optical density values of healthy and attacked trees. The beetle attacked trees have a unique spectral signature that can be detected on color-IR photographs ap-

proximately three months after initial attack when the trees still support visually normal green foliage.

55. Hall, P.M., P.A. Murtha and J.A. McLean, 1981

Remote sensing of Douglas-fir trees newly infested by bark beetles

Proceedings of the Eighth Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1981, April 21-23. Luray, Virginia. American Society of Photogrammetry. pp. 91-98.

Damage: Douglas-fir bark beetle
Sensor: Color-IR film
Area: Tranquille River area of British Columbia

Color-IR 70-mm wing-tip aerial photography at a scale of 1:1000 and flown approximately three months after possible insect attack was analyzed with a Macbeth TR-524 Transmission Reflectance Densitometer. The results indicate that Douglas-fir trees which have been successfully attacked by beetles can be detected on color-IR photographs about three months after the initial attack when the trees still support green, apparently healthy foliage.

56. Hamilton, D.A. 1981

Large-scale color aerial photography as a tool in sampling for mortality rates

U.S. For. Serv. Intermount. For. Range Exp. Stn. Research Paper INT-269

Damage: General Mortality
Sensor: 70-mm color photography
Area: Coeur d'Helene National Forests, U.S.A. (3 flight lines 2.4-3.2 km long)

Mortality rates specify the proportion of trees with a given set of characteristics that are expected to die in a fixed time interval. Results indicate that 1-year mortality trees can be dated and species can be assigned to green trees and to 1-year mortality trees with acceptable accuracy on 70-mm color photography at scales of 1:1600 and 1:2400. Attempts to date 2-year mortality trees on either scale photography were unsuccessful.

57. Harris, John W.E. 1972

High-level photography for forest insect damage surveillance in British Columbia

Proceedings of the First Canadian Symposium on Remote Sensing. 1972, February. Ottawa, Ontario. Dennis White *Ed.* Canada Centre for Remote Sensing, Department of Energy, Mines and Resources, Ottawa. pp. 145-148.

Damage: Forest Insect
Sensor: Color, Color-IR small scale photography
Area: British Columbia

Ultra-small scale (1:160 000) aerial photography of selected areas in British Columbia was examined for detection of forest damage. Infestations caused by western hemlock looper, mountain pine beetle and balsam woolly aphid and flooding damage were identified on color negative film. Color-IR did not provide a good comparison because of its poor quality.

58. Harris, J.W.E. 1974

Small-scale imagery in forest pest surveys in British Columbia

Can. Surveyor 28:126-127

Damage: Forest pests - General
Sensor: Small scale aerial color photography and ERTS imagery.
Area: British Columbia

The boundaries and intensity of a variety of forest pest infestations can be delineated on small scale (1:137 000) color photographs. Some infestations can also be seen on ERTS-1 imagery enlarged to 1:500 000 scale. Included are good examples of color photographs and ERTS-1 imagery.

59. Harris, J.W.E., A.F. Dawson and D. Goodenough 1978

Evaluation of Landsat data for forest pest detection and damage appraisal surveys in British Columbia

Can. For. Serv. Pac. For. Res. Cent. Inf. Rep. BC-X-182. 12 pp.

Damage: Forest pests
Sensor: Landsat MSS data
Area: British Columbia

Color composite images of Landsat MSS bands were examined visually and on digital computer compatible tapes for the detection of heavily damaged trees identified on color and color-IR aerial photographs. The visual classification of color composite imagery proved superior to digital classification. Authors conclude that pest damage detection from Landsat imagery was not sufficiently accurate to be of significant assistance in mapping or assessing forest pest damage.

60. Harris, J.W.E. and A.F. Dawson, 1979

Evaluation of aerial forest pest damage survey techniques in B.C.

Can. For. Serv. Pac. For. Res. Cent. Inf. Rep. BC-X-198. 22 pp.

Damage: Defoliation and dying or dead trees
Sensor: Aerial photography and sketch mapping
Area: British Columbia

This paper describes two aerial survey techniques used by the Forest Insect and Disease Survey in British Columbia: aerial sketch mapping and aerial photography. In aerial sketch mapping from small aircraft the observer sketches on topographic map areas that are defoliated, discolored, or have dead trees, and estimates the number of affected trees. Aerial photographs provide a permanent, accurate record and permit a detailed examination. A comparison of these two survey methods often shows different results. Supplementary aerial photography is recommended to improve aerial sketch mapping techniques.

61. Harris, J.W.E., A.F. Dawson and R.G. Brown. 1982

Evaluation of mountain pine beetle damage using aerial photography. Flathead River, B.C. 1980

Can. For. Serv. Pac. For. Res. Cent. Inf. Rep. BC-X-228. 10 pp.

Damage: Mountain pine beetle
Sensor: Color aerial Photography
Area: Flathead River, British Columbia

Assessment of mountain pine beetle damage in the Flathead River Valley, B.C. (a 14 750 ha area) was conducted in 1980 using 26 1-ha photo-plots on 1:5000 scale color aerial photographs and nine 0.25-ha ground subplots. The area was sketch mapped and photo-plots were established in affected areas on a grid pattern for the multi-stage sampling. The beetle killed pine were counted on the 26 photo plots and ground-corrected by multiplying by the average of the ground sub-plots ratios. Sampling error was 18.5% for tree count and 38.9% for volume. An improved sampling design, based on these results, experience using a 1:6000 scale 70-mm color photography with sketch mapping is also described.

62. Hart, W.G., S.J. Ingle, M.R. Davis, C. Mangum, A. Higgins and J.C. Boling, 1971

Some uses of infrared aerial color photography in entomology

Proceedings of the Third Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1971, March 2-4. University of Florida, Gainesville, Florida. Abraham Anson *Ed* American Society of Photogrammetry. pp. 98-113.

Damage: Insects and Mites (crop pests)
Sensor: Color-IR aerial photography
Area: Texas, USA

Color-IR aerial photography was used for the detection of three species of insects (brown, soft scale and mealy bugs) on citrus trees and two spe-

cies of ants (harvester and Texas leaf cutting ants) in pastures and evaluation of the effects of control applications.

63. Heller, Robert C. 1971

Color and false color photography: Its growing use in forestry

Application of Remote Sensors in Forestry. Joint Report by the Working Group on Application of Remote Sensors in Forestry. International Union of Forest Research Organizations, Section 25: 37-55.

Damage: Forest insects and diseases
Sensor: Color and Color-IR
Area: Various areas in USA

Some forestry applications of color and color-IR photography are described and the usefulness of small, medium and large scales for damage detection, forest species identification, land classification, hydrology and mensuration are rated as "not useful," "good" and "fair."

64. Heller, Robert C. 1975

Remote sensing as an inventory tool for forest insect surveys

Proceedings of a conference on Monitoring Forest Environment through Successive Sampling. 1974, June 24-26. Syracuse, New York. State University of New York. pp. 321-343

Damage: Insect - Balsam woolly aphid, spruce budworm, pine beetle (Mountain, western and southern)
Sensor: Color and Color-IR aerial photography
Area: USA (N. Carolina, Minnesota, S. Dakota, California)

The author provides A review of "Eyeball Survey" (air sketching) and application of color and color IR aerial photography for detecting insect infestations of coniferous forests (Balsam woolly aphid, spruce budworm and pine beetles) conducted in various states. General findings are:

1. Normal color film is as effective in detecting bark beetle infestations as color-IR film in western United States at scales of 1:5840 or larger. At small scales, Color-IR is better.

2. If small infestations of one or two trees can be overlooked, a scale of 1:32 000 is most efficient. If single trees, whose foliage is changing color, need to be detected, a scale of 1:8000 should be used with normal color or color-IR film.

3. Neither normal color or color-IR film is useful as a previsual detector of stress in conifers caused by bark beetle.

4. The progress and trend of the epidemic could be mapped from year to year to demonstrate the disintegration of a stand of ponderosa pine where no management action (thinning) or control was used to reduce beetle populations.

65. Heller, Robert C. 1978

Case application of remote sensing for vegetation damage assessment

Photogramm. Eng. Remote Sens. 44:1159-1166

Damage: All types
Sensor: Aerial photography, MSS Imagery
Area: N/A

Based on a review of some 20 studies involving assessments of vegetation damage by remote sensing methods, the author identifies the advantages, pitfalls, current practical applications and future possibilities of the use of remote sensing for this purpose.

Advantages: The use of many parts of the electromagnetic spectrum, saving of time, money and manpower; ability to cover large areas; the use of successive remote sensing surveys to follow damage trend.

Pitfalls: The overselling of remote sensing techniques without adequate quantitative data showing errors of estimate at predefined confidence limits; use of very expensive remote sensing systems on a transitory phenomenon; the inability

of some Landsat users to recognize that reflectance values are relative subject to atmospheric attenuation and amplified signals; poor design of Landsat wave bands for vegetation damage assessment; a need for better statistical techniques to check classification accuracies; the use of color or color-IR films to obtain previsual detection of coniferous tree damage.

Current practical applications for assessing vegetation damage include: Visual observation techniques; color and color-IR photography; multi-stage sampling, and risk rating systems.

Future remote sensing possibilities: Increasing standardization of color and color IR photography and greater use of small scale; the availability of lightweight, inexpensive radar and laser altimeter with better electronic guidance systems; faster service for receipt of Landsat data products; improved Landsat computer classified images; better resolution on Landsat D; improvements in other sensors - SLAR, charge coupled detectors and microwave imagers.

66. Heller, Robert C. and Robert V. Bega, 1973

Detection of forest diseases by remote sensing

J. For. 71:23-26.

Damage: Air pollution, Dutch Elm disease, oak wilt, dwarf mistletoe, ash dieback, *Fomes annosus*
Sensor: Color and Color-IR films
Area: U.S.A.

Some recent studies which demonstrate that color and color-IR films can distinguish between healthy and disease-stressed vegetation and detect air pollution injuries, oak wilt, dwarf mistletoe, ash dieback, Dutch elm disease, *Fomes annosus* and other (white pine blister rust, beech bark scale disease and root rot of Douglas-fir) are reviewed. Over 20 references are cited.

67. Heller, Robert C., and Wayne A. Miller. 1977

Color Infrared photos define site conditions favourable for Douglas-fir tussock moth outbreaks

Proceedings of the Sixth Biennial Workshop on Aerial Color Photography in the Plant Sciences and Related Fields. 1977, August 9-11. Fort Collins, Colorado. American Society of Photogrammetry. pp. 43-52.

Damage: Douglas-fir tussock moth
Sensor: Color-IR Photography
Area: Oregon, Washington and Idaho, U.S.A.

Analysis of large scale (1:4000) color-IR aerial photography indicated that the probability of stands being defoliated is significantly higher for southeasterly exposures, lower elevations, open stands, multi-storied stands and positions on or near ridgetops.

68. Heller, Robert C., and Steven A. Sader, 1980

Rating the risk of tussock moth defoliation using aerial photographs

US Dept. of Agriculture, combined forest pest research and development program. Agriculture Handbook No. 569. 22 pp

Damage: Tussock moth defoliation rating
Sensor: Color aerial photography
Area: Oregon and Washington States

Risk rating procedures to determine which forest stands in a large management unit are most likely to be defoliated by the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) are described. The work is based on the analysis of eight physiographic and stand variables that tend to favour the development of tussock moth outbreaks: aspect, slope, elevation, crown diameter, crown density, topographic position, stand purity, and radiation index (the phase shift angle of the aspect data which express the amount of radiation reaching the plot). Five risk classes [high, moderately high, moderate, moderately low and low] show the range of probability of defoliation in 20 percent intervals (from 100 to 0).

69. Hobbs, Alison J., 1983

Effects of air-photo scale on early detection of mountain pine beetle infestation

A Thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in the Department of Forestry. The University of British Columbia, July 1983. 137 pp.

Damage: Mountain pine beetle
Sensor: Color-IR photography
Area: Tranquille River, B.C.

Four scales (1:1000, 1:2000, 1:3000 and 1:4000) of 70-mm color-IR positive transparencies were analyzed visually and by densitometric techniques to determine if symptoms of incipient mortality could be detected from green-foliaged trees following attack by mountain pine beetle. Resulting separation of healthy from attacked trees was achieved with an overall accuracy of 89% at 1:1000, 83% at 1:2000, 91% at 1:3000, and 85% at 1:4000.

Densitometric interpretation of the photographic data indicates a significant reduction in the reaction of the film dye-layers to reflected light with a decrease in scale.

70. Hogan, Harland E. and Robert P. Madding, 1978

Detection and Mapping of spruce budworm infestation in Northern Wisconsin using digital analysis of Landsat data

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 197-219.

Damage: Spruce Budworm
Sensor: Landsat MSS, Color & Color-IR 780-mm photography
Area: Northern Wisconsin, USA

A 325 km² area of spruce budworm infested stands in northern Wisconsin was analyzed on digital Landsat tapes using a maximum liklihood classification program. Color and Color-IR 70-mm aerial photography, scales 1:78 000 and 1:48 000 provided a record of ground conditions. Nine resource classes were identified including two levels of coniferous infestation: extensive and moderate. The location and spatial coverage of all resource classes was fairly accurate. The class representing extensive infestation was unable to distinguish between different species exhibiting defoliation properties similar to the fir and spruce. The results indicate that the LANDSAT MSS imagery can be used to identify and map areas of coniferous infestation but supplementary methods are required to determine the type and severity of defoliation.

71. Hoover, D.L. 1974

Remote sensing as a tool in appraising right of way damages

Proceedings of the Second Canadian Symposium on Remote Sensing. 1974, April 29-May 1. University of Guelph, Guelph, Ontario. G.E. Thompson *Ed.* Canadian Remote Sensing Society. pp. 333-335.

Damage: Pipeline construction
Sensor: Color and color-IR
Area: Alberta

Damage to forest and field crops caused by the construction of a gas pipeline was assessed from 1:10 000 scale color and color-IR aerial photography. A stereo plotter provided accurate measurements for quantification of damage intensity.

72. Hopkins, Paul F., L.P. Abrahamson and W.L. Johnson, 1980

Detection and classification of Scleroderris canker in pine stands using aerial photography

Technical Papers of the Fall Technical Meeting. 1980, October 7-10. Niagara Falls, New York. American Society of Photogrammetry. pp. 383-394.

Damage: Scleroderris canker - Red and Scotch pine
Sensor: 70-mm color and color-IR photography, scales 1:12 000 and 1:6 000

Area: Northern New York State, U.S.A.

Eight 10-acre plots with known infection levels by the fungus Scleroderris were interpreted on 70-mm color and color-IR aerial transparencies. Five infection levels (severe, heavy, medium, light and very light), the identifying characteristics (tree mortality, color variation, edge tree appearance, nearby small pine trees, small thin crowns, stand density, texture, and color of the stand), and the relationship between identifying characteristics and the infection levels of the stand were defined and used to develop photo interpretation keys.

Detection accuracies in excess of 90% and classification accuracies greater than 80% were obtained with inexperienced personnel. The medium scale (1:12 000) was approximately as effective as the large scale (1:6 000) as long as a 4X magnification or greater was used with the medium scale.

73. Hostetler, Bruce B. and Robert Young, 1979

Estimation procedures for determining annual tree mortality caused by the mountain pine beetle (*Dendroctonus ponderosae*)

For Insect and Disease Management, State and Private Forestry Rocky Mountain Region. U.S. For. Serv. Tech. Rep. R2-20. 25 p.

Damage: Mountain pine beetle mortality
Sensor: Color aerial photography (1:6 000)
Area: The Black Hills of South Dakota and Wyoming

Multistage sampling techniques were used in 1978 to estimate ponderosa pine mortality caused by the mountain pine beetle in the Black Hills of South Dakota and Wyoming. Using aerial sketch mapping the survey area of 649 800 a was stratified into three intensity classes based on the estimated number of dead trees per acre. Each of the two highest intensity classes or strata were sampled from large scale (1:6 000) color aerial photographs and on the ground. Samples were selected using systematic random procedures in the first stage and probabilities proportional to size in the second stage.

Correlations between photo and ground counts were very good for each stratum sampled. On the 303 000 acres sampled, an estimated 318,000 ponderosa pine representing a volume of 5,629,000 cubic feet were killed in 1978. These numbers and volume estimates had standard errors of 4.2 and 7.2 %, respectively.

74. Hostrop, Bernard W. and Tad Kawaguchi. 1971

Aerial color in forestry

Photogramm. Eng. 37:555-563

Damage: General tree mortality
Sensor: Color aerial photography
Area: Examples of black and white and color photographs of Snow Basin, Utah

A general discussion of advantages of color aerial photography in the development of areas for new timber harvest methods, soil and watershed studies, development of range and reforestation area, planning land development and stream and fish habitat studies. Color provides a significant increase in accuracy of species identification and identification of dead trees.

75. Houston, David R. 1975

Aerial inventory of forest tree diseases

Proceedings of a conference on Monitoring Forest Environment through Successive Sampling 1974, June 24-26. Syracuse, New York. State University of New York. pp. 344-354.

Damage: Forest tree diseases: oak wilt, root rot (Douglas-fir and pines), dwarf mistletoe, air pollution injury, basal canker of white pine and beech bark disease;
Sensor: Color and Color-IR aerial photography, Thermal IR and MSS (Review)
Area: Various parts of USA (review) N/A

Following a comprehensive discussion of some 44 papers dealing with the progress in remote

sensing for inventory of diseased trees, the author states: 1) normal color films record reflections in the visible portion of electromagnetic spectrum (0.4-0.7μ), while color IR films are sensitive to reflection in the visible and in the invisible near-infrared portion of the spectrum (0.4-0.9μ), 2) Reflectance from healthy foliage differs with tree species and leaf age. In all cases, although visible reflectance is strong in the green region, the major reflectance from leaves is in the near-infrared portion of the spectrum. 3) Although studies with annual crops indicated good success in detecting pre-visual symptoms (changes in infrared reflectance before changes in green reflectance) with color IR films, no good evidence exists for similar results with forest trees. In most cases information recorded on color-IR films has also been recorded on normal color and is therefore visible to the eye.

76. Jackson, H.R., V.R. Wallen, D. Galway and S.W. MacDiarmid, 1974

Corn aphid infestation computer analyzed from aerial color-IR

Photogramm. Eng. 40:943-952

Damage: Infestation levels of cornfields
Sensor: Color-IR photography, scale 1:3 600
Area: Harwich Township near Chatham, Ontario

An automatic computer analysis technique to determine aphid infestation levels in corn fields was developed using photographic color separation and image enhancement procedures from color-IR photographs. Panels of healthy and infested corn fields were selected for enhancement whereby density ranges of the cyan layer were compressed to a high contrast mode. The panels were scanned and the information recorded on magnetic tape and analyzed.

77. James, R.L. and C.A. Stewart. 1981

Root Disease Survey on the Nezperce National Forest, Idaho

U.S. For. Serv. North. Reg. Forest Pest Management Report 81-6. 12 pp.

Damage: Root disease - *Armillaria mellea*
Sensor: Large scale (1:4 000) color-IR aerial photography
Area: Nezperce National Forest, Idaho, USA (about 4 500 ha)

Large scale color-IR photography was used to delineate root disease centers within National Forest inventory subcompartments. These centers were identified as opening in the forest canopy with dead and dying conifers on the margins and snags, windthrown trees, scattered live trees and extensive brush toward the centre. Each centre was ground checked, then photographs were reinterpreted and affected area calculated.

78. Jano, A.P. 1982

Practical Applications of remote sensing for forest pest damage appraisal

Proceedings of a Seminar on Uses of Remote Sensing in Forest Pest Damage Appraisal. 1981, May 8. Edmonton, Alberta. Can. For. Serv. North. For. Res. Cent. Inf. Rep. NOR-X-238: 30-39.

Damage: Spruce budworm, Hemlock looper, *Fomes annosus*
Sensor: Color and Color-IR
Area: Ontario

Normal color and color-IR aerial photography is the most common remote sensing technique for the assessment of forest damage in Ontario. Three case studies conducted by the Ontario Centre for Remote Sensing are described in detail. They include the appraisal of hemlock looper from 1:20 000 and 1:8 000 scale color and color-IR photography, detection and identification of *Fomes annosus* damage in red pine plantations from 1:8 000 scale color-IR photography taken with 35-mm, 70-mm and 230-mm format aerial cameras, and spruce budworm damage studies using color-IR film at scales ranging from 1:2600 to 1:6000. These scales were found to be sufficient for the recognition of spruce budworm damage survey: 1:8000 for detailed assessment, and 1:20 000 for damage delineation and mapping.

79. Kenneweg, H. 1978

Prognose durrebedingter Mortalitat in Buchenbestanden und Inventur forstlicher Durrenschaden mit Hilfe von IR - Farbluftbildern

Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment. G. Hildebrandt and H.J. Boehnel *Eds.* 1978, July 2-8. Freiburg, Federal Republic of Germany. International Archives of Photogrammetry. 22: 2027-2044.

Damage: Drought
Sensor: Color-IR photography
Area: 20 km² in Hessen, West Germany

Drought damage in beech stands was mapped from color-IR aerial photographs. Each tree was evaluated in regard to damage symptoms, mainly discoloration and loss of foliage, and identified in the field. The degree of drought damage was related to the soil conditions.

80. Kenneweg, H. 1971

Color and false-color photography: its growing use in forestry - European view

Application of Remote Sensors in Forestry. Joint Report by the Working Group on Application of Remote Sensors in Forestry. International Union of Forest Research Organizations, Section 25: 57-73.

Damage: Forest damage - General
Sensor: Color and color-IR photography
Area: Various examples

Recent European applications of color aerial photography are reviewed. The large scale (1:5000 to 1:7000) color-IR has been successfully applied in the detection of forest damage caused by insects, fungus diseases and abiotic agents (air pollution).

81. Kirby, C.L. 1982

Some developments in remote sensing at the Northern Forest Research Centre

Proceedings of a Seminar on Uses of Remote Sensing in Forest Pest Damage Appraisal. 1981, May 8. Edmonton, Alberta. Can. For. Serv. North For. Res. Cent. Inf. Rep. NOR-X-238: 40-42.

Damage: N/A
Sensor: N/A
Area: N/A

This paper describes the research and development in remote sensing during the past 10 years, which includes multistaged and multiphased inventory approaches, digital and optical satellite image interpretation, small scale color-IR aerial photography, large scale photo sampling and computer mapping.

The only successful detection of forest damage on Landsat was red belt, while on 1:100 000 scale color-IR photographs it was possible to detect forest damage "where the trees had been turned red by flooding in patches as small as 0.1 ha on the original positive transprencies."

82. Klein, William H. 1982

Estimating bark beetle-killed lodgepole pine with high altitude panoramic photography

Photogramm. Eng. Remote Sens. 48:733-737

Damage: Mountain pine beetle
Sensor: Color-IR panoramic photography
Area: South-central Montana, USA

Panoramic color-IR aerial photography and conventional survey methods (sketch mapping and large scale color aerial photography) were used for damage assessment of lodgepole pine stands attacked by mountain pine beetle. A three-stage variable probability design was used with the panoramic aerial photography viewed under 8X to 10X stereoscopic magnification. Both survey methods worked equally well. The conventional survey had a lower standard error than the optical bar survey. The overall cost of conventional aerial photography was much lower than the high altitude panoramic optical bar photography ($3200 and $16376 respectively).

83. Klein, William H., Wilmer Bailey, Emmet Wilson and Irven E. Duggan, 1978

Efficiency of two high elevation camera systems for assessment of insect-caused tree mortality

U.S. For. Serv. Methods Applications Group, Forest Insect and Disease Management. Davis, California. Report 78-3. 12 pp.

Damage: Bark beetle
Sensor: Color-IR
Area: Sierra Nevada, California, USA

Color-IR aerial photography taken with an ITEK KA80A panoramic (Optical Bar) camera and an ACTON HR-732 frame camera with two U-2 aircraft flown at an altitude of 65 000 ft. were evaluated to determine their efficiency in quantifying bark beetle-killed timber. Rear-projection viewers were used for estimating tree mortality and infestation levels and comparison of two formats. The best relationship was with stratification on the optical bar format, but the technique was too time-consuming to be operationally efficient.

84. Klein, W.H., D.D. Bennett and R.W. Young, 1980

Evaluation of panoramic reconnaissance aerial photography for measuring annual mortality of lodgepole pine caused by mountain pine beetle

US For. Serv. Methods Applications Group, Forest Insect and Disease Management. Davis, California. Report 80-2. 21 pp

Damage: Mountain pine beetle
Sensor: Optical Bar panoramic color-IR photography
Area: National forests in Montana, U.S.A.

High elevation (65 000) panoramic color-IR aerial photography was used for the assessment of mountain pine beetle damage in 2000 km² area in Montana. Characteristics of panoramic aerial photography and photo interpretation procedures are described. The results indicate that this unconventional photography can be effectively used to provide precise estimates of mountain pine beetle-caused annual mortality of lodgepole pine over large areas.

85. Klein, William H., Dayle D. Bennett and Robert W. Young. 1978

Multiphase Airphoto Assessment for Annual Losses Caused by the Mountain Pine Beetle in Lodgepole Pine

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp 355-367.

Damage: Mountain pine beetle
Sensor: Large scale (1:6000) color ektachrome
Area: Idaho, USA

One of the pilot projects to measure annual mortality caused by the mountain pine beetle is described. A stratified double sampling system included aerial sketch mapping on a 1:126 720 scale planimetric map, stratification into three intensity classes, selection of photo plots (16 ha each), acquisition of 1:6000 scale color photography of photo plots, subdivision of photo plots into sixteen 1-ha sub-plots, stereoscopic examination of sub-plots, tree count, field examination of 20 randomly selected sub-plots and compilation of mortality. The standard error for number of trees was 8.2% and for volumes 9.7%.

86. Krauth, Ekkehart and Hans Schreiber, 1974

Recognition of fire-blight diseases by means of aerial photography

Proceedings of the Symposium on Remote Sensing and Photo Interpretation. 1974, October 7-11. Banff, Alberta. Canadian Institute of Surveying. pp 455-465.

Damage: Fire-blight
Sensor: Color and Color-IR 70-mm photography
Area: Schleswig-Holstein area, Germany

Large scale (1:1500) color and color-IR 70-mm aerial photographs were analyzed for the early detection of fire-blight infestations in living brushwood using color densitometric measurements. The characteristic symptoms of disease were

recognized from the differences of color densities. Using the cluster method, the differences may be presented graphically to determine the best criteria for classification of infected plants.

87. Lachowski, Henry M. and S.H. Anderson. 1979

Assessment of fire damage within Seney Wildlife Refuge from aerial photography and Landsat imagery

Proceedings of the Seventh Biennial Workshop on Aerial Color Photography in the Plant Sciences and Related Fields. 1979, May 15-17. University of California, Davis, California. American Society of Photogrammetry. pp. 221-228.

Damage: Fire
Sensor: Digitally processed Landsat data and color-IR aerial photography
Area: About 400 km² in Seney Wildlife Refuge, Michigan, U.S.A.

Low altitude color-IR aerial photography and digitally processed MSS LANDSAT data were used to map post-fire vegetation and land cover conditions. A generalized land cover map, showing fire intensity classes (light, moderate, hard surface burn, and organic burn) and five land cover types (mixed forest, brushland, grassland, wetland and water) with the area measurements for each class, was compiled from digital analysis of Landsat MSS data. The color-IR photography was used for detailed mapping of post-fire vegetation and for determination of changes resulting from the fire. The combined use of the two information sources and ground observations proved to be very effective in the assessment of post-fire land cover conditions.

88. Larcher, G. and N. Antore, 1978

Remote sensing of some forest damaged plants by false color photography, spectroradiometry visible and near IR

Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment. G. Hildebrandt and H.J. Boehnel *Eds.* 1978, July 2-8. Freiburg, Federal Republic of Germany. International Archives of Photogrammetry. 22: 751-760.

Damage: Damaged foliage (oak, birch, beech and bracken leaves)
Sensor: Color-IR photography, spectroradiometer
Area: Roumare forest, France

Color-IR photographs taken from a helicopter were used to map damaged forest stand in the Roumare forests. The relative spectral distribution of reflected energy by oak, birch, beech and bracken foliage was measured with a 10-band spectroradiometer, built by the Laboratoire d'Optique Physique, Institute Scientifique de Haute Normandie at U.E.R. Sciences, Mont-Saint-Aignan, France. The measurements were made in the laboratory and in situ (from helicopter) to determine the most suitable spectral bands which would register the degree of damage.

89. Leckie, D.G. and F.A. Gougeon, 1982

Assessment of spruce budworm defoliation using digital airborne MSS data

Proceedings of the Seventh Canadian Symposium on Remote Sensing. 1981, September 8-11. Winnipeg, Manitoba. William G. Best and Sue-Ann Weselake *Eds.* Canadian Aeronautics and Space Institute. pp. 190-196.

Damage: Spruce budworm
Sensor: MSS — airborne
Area: Cape Breton Island, Nova Scotia

Airborne 11-channel MSS digital data were used in the assessment of spruce budworm defoliation of spruce-fir stands. In the supervised classification of low altitude (1800 m) data four levels of defoliation were classified with about 25% error. The near IR channels, particularly channel 9 (0.77-0.90 m) combined with channel 3 (0.45-0.50 m) provided best separations of defoliation classes. An unsupervised technique of high altitude (7600 m) data was able to discriminate two broad levels of defoliation.

90. Lee, Y. Jim , E.T. Oswald and J.W.E. Harris, 1974

A preliminary evaluation of ERTS imagery for forest land management in British Columbia

Proceedings of the Second Canadian Symposium on Remote Sensing. 1974, April 29-May 1. University of Guelph, Guelph, Ontario. G.E. Thompson *Ed.* Canadian Remote Sensing Society. pp. 87-101.

Damage: Forest Pests
Sensor: MSS ERTS-1
Area: British Columbia

The MSS ERTS imagery was evaluated for a potential use in mapping logging activities, plant communities and pest damage. The pest damaged forest stands were identified only where the damage appeared most distinctly, as an extensive western spruce budworm infestation in the Pemberton area. On standard color composite prints or on enhanced bands 4, 5 and 6 the damaged areas were recognized from a distinct reddening of the foliage.

91. Lee, Y. Jim, and John F. Wear, 1978

Microdensitometry to identify Douglas-fir tussock moth defoliation on Color IR aerial photos

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 181-195.

Damage: Tussock moth defoliation
Sensor: Color-IR aerial photography
Area: Eastern Washington, USA

Color-IR transparencies showing Douglas-fir tussock moth defoliation in Douglas-fir stands were scanned on the CCRS Scanning Densitometer using blue, green and red filters. The resulting digital imagery was analyzed with the aid of the Image-100 system. Defoliated trees in densely forested stands were easily identified by their unique white tone. In partially open stands, where the image densities of the defoliated trees are similar to the ground vegetation, only the upper one-third of defoliated trees could be detected, and the assessment of individual host trees was not possible.

92. Leupold, R.C., R.P. Herbst, J.B. Mathies and R.J. Kohut, 1978

Use of color infrared aerial photography for documenting baseline vegetation stress in environmental impact assessment

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 369-380

Damage: Vegetation stress
Sensor: Color-IR (large scale)
Area: USA

This paper discusses the use of color-IR transparencies, scale 1:7200 in stereoscopic analysis for species differentiation, detection of vegetation stress caused by insects, diseases, storm and frost damage, weed competition, moisture deficiency or surplus, and other environmental conditions.

93. Lillesand, Thomas, M. Robert H. Brock, Jon. L. Roberts and William L. Johnson, 1975

Tree stress detection through spectral ratioing of color film records

Proceedings of the Fifth Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1975, August 19-21. EROS Data Center, Sioux Falls, South Dakota. American Society of Photogrammetry. pp. 79-107.

Damage: Tree stress (ozone fumigation, Fomes annosus)
Sensor: Color-IR (close range) photography
Area: Syracuse, N.Y.

The authors report on the research in the use of close range (1 m) photography to monitor spectral and spacial response of young poplars to ozone fumigation and the application of an Experimental Photometric Interpretation Console

(EPIC) in bi-band spectral rationing of color film layer records acquired under field conditions for an enhanced detection of red pine root rot and potassium deficiency in white spruce.

94. Lillesand, Thomas M., Bov Bang Eav and Paul D. Manion, 1979

Quantifying urban tree stress through microdensitometric analysis of aerial photography

Photogramm. Eng. Remote Sens. 45:1401-1410

Damage: Urban tree stress
Sensor: Color and color-IR photography (70mm)
Area: Syracuse, N.Y. (four sites)

The pilot project to determine if and how optical density measurements made from color and color-IR 1:6000 scale aerial photography relate to on-the-ground observations of stress in 1156 urban shade trees is described. Factor analysis was used to develop quantitative "stress indexes" based on the ground data. Multiple regression was used to develop a statistical model for predicting the stress indexes on the basis of image density measurements. Tests of the modelling process indicated that aerial predictions were as reliable as ground estimates, particularly under drought conditions.

95. Lillesand, Thomas M., Douglas E. Meisner, David W. French, and William L. Johnson, 1981

Evaluation of Digital Photographic Enhancement for Dutch Elm Disease Detection

Photogramm. Eng. Remote Sens. 48:1581-1592

Damage: Dutch elm disease
Sensor: Color-IR photographs (digitally enhanced)
Area: St. Paul, Minnesota

Color-IR 70-mm aerial photographs, scales 1:6,000 and 1:12,000 of known Dutch elm disease infestations were analyzed visually and by densitometric procedures. Scanning densitometer data from the photographs were processed using three enhancement techniques: color contrast stretch, two-band spectral ratioing, and multiple discriminant analysis. The numerically processed data were reconverted to image forms using a high resolution color film recorder. The computer enhanced imagery increased the expression of subtle color variations within and between crowns, but only nominally improved detection accuracy. The factor limiting detection from vertical photography appears to be the inconsistency, not the subtlety, in which Dutch elm disease is manifested as crown color variation.

96. Mason, Garland N. 1977

Southern pine beetle stand hazard projection from LANDSAT, high altitude, and small format aerial photography

Proceedings of the Sixth Biennial Workshop on Aerial Color Photography in the Plant Sciences and Related Fields. 1977, August 9-11. Fort Collins, Colorado. American Society of Photogrammetry. pp. 43-52.

Damage: Southern pine beetle
Sensor: LANDSAT, high altitude and small format photography
Area: 16,000 sq. mile area in Texas, U.S.A.

A multi-level approach to test the feasibility of stand hazard predictions, using LANDSAT (Level I) for a preliminary forest survey is described; 1:60,000 scale Color-IR photographs for mapping ten 18,000-acre sampling blocks (Level II); sample strips with 35 mm photography covering about 5% of the 18,000 acre blocks for height and species identification (Level III), and in Level IV a precise estimate of tree diameter, BA and total tree count from 35 mm large scale (1:5200) acquired simultaneously with Level III strips.

97. Mason, Garland. N. 1979

Small scale aerial photo stand susceptibility rating for southern pine beetle in East Texas

Proceedings of the Seventh Biennial Workshop on Aerial Color Photography in the Plant Sciences and Related Fields. 1979, May 15-17. University of California, Davis, California. American Society of Photogrammetry. pp. 125-135.

Damage: Southern pine beetle
Sensor: Color-IR and Landsat imagery
Area: East Texas, USA

Application of LANDSAT, Color-IR 1:60 000 scale photography and large scale (1:10 000 and 1:5225) 35-mm sample strips, is described for classification of habitat types, assignment of four southern pine beetle hazard classes (very high, high, moderate, and low), and verification of a research model. More than 25 stand, tree and site characteristics were used as variables in development of predictive equations.

98. McKim, Harlan, L., Lawrence W. Gatto, Carolyn J. Merry and Saul Cooper, 1978

The effect of inundation on vegetation at selected New England flood control reservoirs

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 511-327.

Damage: Inundation
Sensor: Color-IR aerial photography
Area: New England, USA

Color-IR aerial photography at a scale of 1:9800 was used in the assessment of the effect of inundation on forest vegetation. Based on the color-IR reflectance differences between healthy and unhealthy trees, four damage intensity classes were delineated. Damaged trees exhibited blue, brown, green or pink tones on color-IR photographs. The ground transect profiles provided data on the relationship between species susceptibility and inundation time and the vegetative damage is attributed to the duration of inundation and the degree of silting.

99. Mead, R.A., J.L. Smith, J.G.D. Ward and J.H. Ghent, 1979

Development of a system for regional assessment of timber volume loss due to the southern pine beetle using color infrared aerial photography

Proceedings of the Seventh Biennial Workshop on Color Aerial Photography in Plant Sciences and Related Fields. 1979, May 15-17. University of California, Davis, California. American Society of Photogrammetry. pp. 137-149.

Damage: Southern pine beetle
Sensor: Color-IR aerial photography
Area: Central Mississippi, USA

This is a preliminary description of the application of 1:8000 scale color-IR sequential aerial photography to estimate the annual timber mortality caused by the southern pine beetle. Aerial photography of 45 predetermined sampling plots was used to delineate the areas of dying trees and to estimate the crown closure and height of infested stands. Timber volume in each infestation was estimated from aerial photo volume tables. The annual mortality was estimated from a survey of the same areas for two successive years.

100. Merideth, Robert W. Jr. 1981

Doctoral Dissertations Pertaining to Remote Sensing and Photogrammetry: A Selected Bibliography

Photogramm. Eng. Remote Sens. 47:617-629

Damage: N/A
Sensor: N/A
Area: N/A

Doctoral dissertations pertaining to remote sensing and photogrammetry written in the USA and Canada are listed by year (from 1945-1980). Among over 300 titles there are nine (9) dissertations dealing directly with remote sensing and forest damage. For each entry the following information is given: Author, title University name of supervisor, year, abstract (international), Volume/Number, page number.

1. Bajzak, Denes. Detection and appraisal of Damage by Balsam Woolly Aphid on *Abies balsamea* (L.) Mill by means of aerial photography. State University College of Forestry at Syracuse University, 1967, 252 pp. (J.C. Sammi) 28/11-B4369

2. Murtha, Peter A., Near-Infrared Detection of simulated animal damage on conifers, Cornell University, 1968, 95 pp. 29/6-B 1891

3. Thorley, Gene A., The Development of a System for evaluating timber stand mortality trends using sequential aerial color photography, University of California, Berkeley, 1970, 136 pp. 31/10-B 5471

4. Stevens, Alan R., Application of color and color infrared aerial photography to Dutch Elm disease detection, University of Wisconsin — Madison, 1972, 164 pp. (James P. Scherz) 33/7-B3069

5. Douglas, Robert W. Use of high altitude photographs for forest disease detection and vegetation classification within the subboreal forest region, University of Minnesota, 1973, 150 pp. 34/5-B1813

6. Kuman, Ravindra., Emission and refraction from healthy and stressed natural targets with computer analysis of spectroradiometric and multispectral scanner data, Purdue University, 1973, 258 pp (LeRoy Silva, Robert Goulard), 35/1-B262

7. Cook, Jerald J. Natural and stress related temperature variation in *Quercus macrocarpa* and its significance for thermal remote sensing. University of Michigan, 1974, 231 pp. (Charles E. Olson, Jr.) 35/5-B2005

8. Eav, Bov. B., A photographic remote sensing system for the detection and quantification of urban tree stress, State University of N.Y., College of Env. Science and Forestry Lillesand and Tiberius Cunia) 39/1-B8

9. Williams, David H., Computer detection of citrus infestations using aerial color infrared transparencies, University of Texas of Austin, 1977, 173 pp. (J.K. Aggarval) 38/05-B2306

101. Miller, Wayne A. and Robert C. Heller, 1978

Remote sensing approach to identifying preferred Douglas-fir tussock moth (*Orgyia pseudotsugata* McD.) sites

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 311-333

Damage: Douglas-fir tussock moth
Sensor: large scale Color-IR
Area: Blue Mountains (Oregon-Washington), USA

Random lines of 1:4000 scale Color-IR, aerial photography was used to determine whether the forest stands susceptible to attack by the Douglas-fir tussock moth could be identified. Twenty-four Systematically selected groups of three 0.4-ha circular plots along each 10-km flight line were divided into two defoliation classes: defoliated and nondefoliated. Fir stands with a high probability of defoliation were: 1) those at low elevation 2) those on eastern and south-eastern exposure 3) those on or near ridge tops, and 4) those composed of high crown density with large crown diameters in the overstory. Mixed stands were found to be less susceptible than pure-host stands.

102. Moore, W.C. 1974

Analysis of ERTS-1 imagery for wind damage to forests

Proceedings of the Second Canadian Symposium on Remote Sensing. 1974, April 29-May 1. University of Guelph, Guelph, Ontario. G.E. Thompson *Ed.* Canadian Remote Sensing Society. pp. 337-346.

Damage: Blowdown
Sensor: MSS ERTS imagery
Area: Ontario

Visual analysis of MSS ERTS imagery was conducted to delineate the forest areas damaged by strong winds. A linear anomaly visible on bands

4 and 5 was identified as a 2-km-wide and 86-km-long swath of forest damaged by a tornado. In another example, a diazo-overlay enhancement technique was applied to the recognition of a widespread blowdown.

103. Moore, W.C. 1974

Tornado damage to forests: Sudbury, Ontario

Can. Surveyor. 28:126-127.

Damage Wind
Sensor: MSS-ERTS Bands 4 and 5
Area: West of Sudbury, Ontario

Black and white prints of Band 4 and 5 ERTS imagery were used to map the extent of vegetation damage along an 86-km-long and 2-km-wide tornado track.

104. Moore, W.C. 1974

Detection and delineation of natural disasters: landslides and floods

Can. Surveyor. 28:180-186.

Damage: Landslide and flood
Sensor: ERTS (Bands 6 and 7) enlargements
Area: Alberta, Ontario, Quebec and New Brunswick

Three known large landslides (Frank Slide, Alberta, St. Jean Vianney, Quebec, and South Nation River landslide in Ontario) and a disastrous flood in the Saint John River in New Brunswick were identified in single bands (6 and 7) of ERTS imagery enlarged to a scale of 1:400 000 and compared with recent medium scale photographs. The detection was based on the *a priori* knowledge.

105. Morin, Jean-Louis and Marshall D. Ashley. 1979

Small scale aerial photography for planning spruce budworm spray blocks

Proceedings of the Annual Meeting of the American Society of Photogrammetry. 1979. pp. 469-476.

Damage: Spruce budworm
Sensor: Panchromatic, small-scale
Area: Maine, U.S.A.

The use of small scale (1:62,500 and 1:80,000) panchormatic aerial photography to delineate non-softwood forest types for planning spruce budworm chemical spray programs is described. Up to 30% of the forest area proposed for spraying could be eliminated through photo-identification of non-host forest types on 1:62,500 Pan aerial photographs. Results from 1:80,000 scale photography were not satisfactory.

106. Murtha, P.A. 1971

Air photo interpretation of SO_2 foliage damage — North Thompson River Valley, British Columbia

Confidential report submitted to the Vice-President, Canadian National Railways, on the areal extent of SO_2 damage resulting from the train wreck July 19, 1971 at Vinsula, B.C.

Can. For. Serv. For. Manage. Inst. Ottawa, Ontario. 22 pp

Damage: Sulfur dioxide fumes
Sensor: Color-IR
Area: about 44 km² (North of Kamloops, B.C.)

Dead foliage on trees was used as an indicator to map the areal extent of sulfur dioxide fume damage which resulted from burning elemental sulfur from a train wreck. Four levels of damage were mapped on 1:12 000 scale color-IR aerial photography: heavy, medium, light and very light. Black cottonwood, which is a common tree in the river valley, was very susceptible to the sulfur dioxide damage and therefore was a good indicator of the limits of the affected area. Topography, exposure of a tree, canopy density, and local wind patterns influenced the susceptibility of the foliage to damage. None of the photographs taken several days and two weeks after the train wreck revealed any tree mortality.

107. Murtha, P.A. 1971

A key to air photo interpretation of forest damage in Canada

Proceedings of the Third Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1971, March 2-4. University of Florida, Gainesville, Florida. Abraham Anson Ed. American Society of Photogrammetry. pp 166-180.

Damage: General
Sensor: Aerial Photography.
Area: Canada

The use of a dichotomous key for the recognition of major damage categories and 29 sub-categories or damage types, based on morphological and physiological damage characteristics is described. This paper is a condensation of the 1972 *Guide to air photo interpretation of forest damage in Canada*, CFS Publ. No. 1292.

108. Murtha, P.A. 1972

Classification of forest damage from air photos

Can. For. Serv. For. Manage. Inst. Ottawa, Ontario

Damage: Defoliation and mortality - various types
Sensor: Medium scale (1:4000) color-IR photography
Area: Petawawa Forest Experiment Station, Ontario

Eleven 1-ha sample plots were examined on 1:4000 scale color-IR 70-mm photographs for damaged trees by an inexperienced and experienced photointerpreter using the original 70-mm transparencies and paper prints. The experienced interpreter recognized four times more damaged trees than the inexperienced interpreter. Author stresses the advantages of original positive transparencies over paper prints.

109. Murtha, P.A. 1972

Thermal infrared line-scan imagery for forestry?

Can. For. Serv. For. Manage. Inst. Inf. Rep. FMR-X-45. 46 pp.

Damage: Forest insect and disease
Sensor: Reconofax IV optical-mechanical line scanner
Area: LaRose Forest, near Ottawa, Ontario

A Reconofax IV optical-mechanical line scanner, with a 3-milliradian indium-antimonide detector (peak sensitivity in the 3- to 5-micron region) was used in the experiments to identify forest sites, types, and tree species, and to detect and appraise forest damage.

The results of image interpretation indicate that while a good deal of information was obtained concerning site variables, the thermal imagery provided little or no information concerning forest types or damage detection. One exception is that IR line scanners record differences in leaf temperature which may be attributed to moisture stress.

110. Murtha, P.A. 1972

A guide to air photo interpretation of forest damage in Canada

Can. For. Serv. Publ. 1292. 65 pp.

Damage: All
Sensor: Aerial photography
Area: Examples from various parts of Canada

Two basic forest damage categories defined on the basis of morphological or physiological change are subdivided into four major damage types:

Type I — trees that are completely, or almost completely, defoliated.

Type II — trees that show some defoliation through the presence of bare branches, or malformation.

Type III — trees that show the foliage as another color which is not consistent with the normal foliage color of the species involved.

Type IV — trees that show no visible sign of damage, but have a deviation from a normal reflectance pattern in the non-visible light range.

Following a literature review on photointerpretation of forest damage and a comprehensive explanation of spectral reflectance and its effect on aerial photographs, the major tree damage types are described in detail. Color, color-IR and black-and-white aerial photographs illustrate the text. A Dichotomous key to air photo interpretation of forest damage types and the index to damaging agents and host species provide a cross-reference for identification of some 25 varieties of tree damage types.

111. Murtha, P.A. 1972

Photo interpretation of tree mortality along the International Boundary: Waterton Lakes National Park

Can. For. Serv. For. Manage. Inst. National Parks Forest Survey Report No. 5. 6 pp.

Damage: Herbicide Tordon 101. tree mortality
Sensor: Color and color-IR aerial photography
Area: Canada-USA Boundary, Waterton National Park, Alberta

Color and color IR photographs, scale 1:6000 were analyzed in 1972 for the assessment of tree mortality caused by a spraying with herbicide Tordon 101 four years earlier along the International Boundary in Waterton Lakes National Park. Strips of dead trees were noted on both sides. 1490 dead trees were counted along the Canadian side and 1236 dead trees were counted on the U.S side of the Boundary.

112. Murtha, P.A. 1972

SO_2 forest damage delineation on high-altitude photographs

Proceedings of the First Canadian Symposium on Remote Sensing. 1972, February. Ottawa, Ontario. Dennis White *Ed.* Canada Centre for Remote Sensing, Department of Energy, Mines and Resources, Ottawa, pp. 71-82.

Damage: Sulfur dioxide
Sensor: Color-IR ultra small-scale photographs
Area: Wawa, Ontario

Color-IR 70-mm aerial photography at a scale of 1:160 000 was used for the assessment of vegetation damage caused by sulfur dioxide fumes from an iron plant near Wawa, Ontario. Four damage zones: Total-kill, heavy-kill, medium damage and light injury were recognized in forest areas. Identification of damage zones was easiest on color-IR photographs, and almost impossible on the black- and-white photographs of the same area. The results were as good as aerial sketch mapping.

113. Murtha, P.A. 1973

Spruce budworm damage in Fundy National Park, New Brunswick

Can. For. Serv. For. Manage. Inst. National Parks Forest Survey Report No. 6. 12 pp + Appendices.

Damage: Spruce budworm
Sensor: Color-IR, 1:10 000 scale aerial photography
Area: Fundy National Park, New Brunswick (about 200 km^2)

Aero-chrome IR aerial photography at a scale of 1:10 000 was used for delineation and mapping of spruce budworm damage in Fundy National Park. This report describes the survey procedures which involved stratification of spruce-fir stands into five defoliation and mortality classes. Volumetric estimates based on field sampling indicate that seven percent of the total cubic foot volume in the spruce-fir stands has been killed.

114. Murtha, Peter A. 1974

Interpretation of vegetation damage, extensively managed lands

Proceedings of the Symposium on Remote Sensing and Photo Interpretation. 1974, October 7-11. Banff, Alberta. Canadian Institute of Surveying. pp 429-437

Damage: Defoliation
Sensor: Various
Area: N/A

This is a discussion paper on the "state-of-the-art" of interpretation of vegetation damage over extensively managed lands as of 1974. Some selected papers are cited on the use of aerial photography and satellite imagery for the recognition of various types of vegetation damage. General principles of damage identification now exist. It is now up to research institutions, governmental bodies, universities and consultants to "accept some of the methods and put them into general use."

115. Murtha, Peter A. 1974

Detection of SO_2 fume damage to forests on ERTS-1 imagery

Can. Surveyor. 28:167-170.

Damage: Sulfur dioxide
Sensor: ERTS-1 imagery, enhanced
Area: Wawa, Ontario

Three damage zones caused by sulfur dioxide fumes were delineated on color enhanced ERTS imagery: total-kill, heavy-kill and medium damage. Band 5 provided the greatest detail for detection of forest damage, followed by bands 4, 6 and 7.

116. Murtha, P.A. 1975

Spectral reflectance deduced from color-infrared photos for forest damage detection

Proceedings of the Fifth Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1975, August 19-21. EROS Data Center, Sioux Falls, South Dakota. American Society of Photogrammetry. pp. 109-116

Damage: Root rot, sulfur dioxide
Sensor: Color-IR
Area: Ontario

The analysis of density patterns of the individual dye layers of color-IR film using subtractive color viewing and density slicing to deduce relative spectral reflectance data for various objects is described. Objects in the test were: exposed sand, a dead red pine killed by *Fomes annosus* root rot, red pine surrounding the dead pine, a row of Scotch pine and a black cherry.

117. Murtha, Peter A. 1976

Vegetation damage and remote sensing: principal problems and some considerations

Photogrammetria. 32:147-156

Damage: N/A
Sensor: N/A
Area: N/A

Principal problems in the application of remote sensing techniques for inventorying and monitoring vegetation damage are related to economics and cost effectiveness; detection reliability, mapping of damage vs. sampling for initial damage detection; association of more than one organism with a single damage effect, or vice versa; overrating health of trees in damaged stands and under-rating in healthy stands and; timing of the survey. Recommendations are based on: more complete economic studies; production of consistent materials with which to work; agreeing on philosophy for forest damage detection; accepting a standard for damage evaluation, and more effective "selling" of present techniques.

118. Murtha, P.A. 1976

Inventory and monitoring of forest diseases and damages by remote sensing — considerations about promising ways to do it

Proceedings of the Sixteenth World Congress of the International Union of Forest Research Organizations. 1976. Oslo, Norway. IUFRO. pp. 385-397.

Damage: N/A
Sensor: N/A
Area: N/A

This discussion paper describes a dynamic, flexible system composed of four phases (airborne,

photo-development, interpretation, and evaluation), and significant factors to be considered in each phase. Throughout the entire system, the overlying premise is that "the airphoto interpreter is aware of possible damage manifestations, their effect on the photographic image, and consequently the interpreter is aware of what to look for."

119. Murtha, Peter A. 1978

Remote Sensing and vegetation damage: A theory for detection and assessment

Photogramm. Eng. Remote Sens. 44:1147-1158

Damage: All types
Sensor: Normal color and Color-IR
Area: N/A

The paper discusses philosophical and technical aspects of remote sensing for assessment of vegetation damage and provides answers to the following questions: 1) What constitutes remote sensing evidence of vegetation damage? 2) How is vegetation damage interpreted from remotely sensed data? and, 3) How can the damage be assessed? The answers to these questions are discussed in detail relevant to normal color and color-IR aerial photography. Consideration is given to details of film reaction to variations in spectral reflectance pattern. Damages showing morphological or physiological changes are discussed relative to spectral reflectance changes and presented as a means to code damage types.

120. Murtha, P.A. 1978

Interpretation of the 1977, large scale, colour-infrared aerial photographs for tree damage, Kitimat Valley, B.C.

Unpublished report prepared for Reid, Collins and Associates Ltd., Vancouver, B.C. 41 pp. + appendix

Damage: Air pollution
Sensor: Color-IR large-scale aerial photography
Area: Kitimat Valley, British Columbia

As a part of the continuing study on fluoride emissions and forest growth around the ALCAN smelter, the forest stands on the west side of the Kitimat Valley were analyzed on 1:2000 scale color-IR aerial photographs and the damaged hemlock trees were interpreted as four major damage types: I — total defoliation; II — partial defoliation; III — a foliage color change; and IV — a near infrared reflectance change. The theory of vegetation damage interpretation is discussed relative to damage types, the effect of damage on spectral reflectance, the effect of reflectance on the film image, and the sequence of damage types for trees affected by air pollution.

121. Murtha, P.A., 1979

Extravisual damage detection?: defining the standard normal tree

Proceedings of the Seventh Biennial Workshop on Aerial Color Photography in the Plant Sciences and Related Fields. 1979, May 15-17. University of California, Davis, California. American Society of Photogrammetry. pp. 179-189

Damage: Defoliation and stress
Sensor: 70-mm color-IR photography (wingtip) and densitometer
Area: Douglas-fir stands, Tranquille Provincial Forest, British Columbia

Densitometric measurements and calculated density ratios from the developed cyan, magenta and yellow dye layers of 1:1200-scale color-IR film were used in the analysis of 354 damaged trees. The ratios were stratified according to the damage classification. Trees were field checked and radial increment cores were used for diameter increment analysis. The diameter increments were related to damage classification. Trees classified as Damage Type III on color 1976 photographs because of their darker or lighter magenta hue, could not be separated visually on the ground in 1978, but showed significantly reduced diameter increments when compared with normal trees.

122. Murtha, P.A. 1980

Photo interpretation of tree damages in the Gross Cap Indian Reservation, near Wawa, Ontario

Unpublished Report prepared for the Union of Ontario Indians. 107 pp.

Damage: Sulfur dioxide pollution
Sensor: Color-IR aerial photography (small and large scales)
Area: Gross Cap Indian Reservation, Ontario (about 30 km^2)

This report, prepared for the Union of Ontario Indians, outlines the interpretation of small (1:63 360) and large (1:3000) scales of color-IR aerial photography for the appraisal of forest damage caused by sulfur dioxide fumes resulting from iron-sintering at Wawa, Ontario. The sulfur dioxide related forest damage was interpreted on 57 photo plots, 0.1 ha in size, selected along three transects. Original transparencies were analyzed with 7X magnification in a Bausch and Lomb zoom 240 stereoscope. In addition, 27 control plots were analyzed along a control transect, located 19km south of the Reserve. The data from the plot counts were used to calculate the plot damage values. Based on the classification of the photo plots, the Reserve was then stratified on small scale aerial photographs according to possible damage zones.

The results indicate that there is about 10% more damaged trees on the Reserve than on the control plots, and 24 plots in the eastern side of the Reserve have approximately 25% more damaged trees. The sulfur dioxide related damage (Damage Type III06) is found in 25% more of the trees on the Reserve, than on the control plots. Generally, the levels of damage vary from a high in the eastern and southeastern parts of the Reserve, to a low in the western and northwestern parts.

Other causes of forest damage (site effect, spruce budworm, birch leaf miner, birch decadence, etc.) are discussed, but they cannot be linked in the patterns interpreted from the air photographs.

123. Murtha, P.A. 1980

Modelling tree damage — type patterns for photo interpretation of SO_2 injury

Internat. Arch. Photogramm. 13:667-679

Damage: Sulfur dioxide
Sensor: N/A
Area: N/A

The known effects of sulfur dioxide on forest trees are reviewed and discussed in photo interpretation terms. Acute and chronic injuries cause many different damage syndromes over short and long terms, and can cause considerable confusion during photo interpretation. However, modelling the 'flow pattern' of the damage syndromes as they progress from initial effects to the final (dead tree) syndrome facilitates interpretation. The generalized flow patterns of sulfur dioxide damage syndromes for coniferous and deciduous boreal trees are described with specific examples.

124. Murtha, P.A. 1982

Detection and analysis of vegetation stresses

Proceedings of a Seminar on Uses of Remote Sensing in Forest Pest Damage Appraisal. 1981, May 8. Edmonton, Alberta. Can. For. Serv. North. For. Res. Cent. Inf. Rep. NOR-X-238: 2-24.

Damage: N/A
Sensor: N/A
Area: N/A

The understanding of the remote sensing data interpretation for vegetation stresses is based on a knowledge of stress, the effect of the stress on the vegetation, strain symptoms, and the capabilities and limitations of the remote sensing techniques. The conceptual problem is the use of the term "previsual detection." This term is correct only where the interpreted symptom eventually becomes visible. Previsual detection implies that near-infrared changes are always followed by visual reflectance changes; however, alterations in the near-infrared are not necessarily followed by visual changes and some previsual symptoms

may never become visual because of vegetation recovery.

125. Murtha, Peter A. 1983

Some air photo scale effects on Douglas-fir damage type interpretation

Photogramm. Eng. Remote Sens. 49:327-337

Damage: Forest strain symptoms (western spruce budworm)
Sensor: Large-scale color-IR
Area: Kamloops, British Columbia

A comparison of strain symptoms detection on 1:1000 and 1:4000 scale color-IR aerial photographs is described. While no significant difference has been found in counts between total number of live trees, dead trees or trees with dead tops, there was a significant difference between counts of tree crowns displaying the subtle damage symptoms indicative of chronic levels of stress. The author concludes that the 1:1000 scale is required for interpretation of the subtle strain symptoms. For counts of dead trees, the scale of 1:4000 would be adequate.

126. Murtha, Peter A. and J.W.E. Harris, 1978

LANDSAT verification of aerial sketch mapping

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 417-427

Damage: Douglas-fir tussock moth
Sensor: LANDSAT MSS, color and color-IR, aerial sketch mapping
Area: Kamloops, British Columbia

Paper describes the use of LANDSAT imagery for mapping heavy and medium zones of forest defoliation. Four LANDSAT MSS bands were used in color-additive viewer, and, by a combination of blue-green-red-red, or white-green-white-red filters, produced color composite images similar to color-IR photographs. The zones of Douglas-fir tussock moth defoliation delineated on enhanced LANDSAT image were comparable to the results of aerial sketch mapping.

127. Murtha, P.A. and R. Trerise, 1977

Four years after: Photo interpretation of the residual effects of SO_2 damage to conifers and hardwoods

Proceedings of the Sixth Biennial Workshop on Aerial Color Photography in the Plant Sciences and Related Fields. 1977, August 9-11. Fort Collins, Colorado. American Society of Photogrammetry. pp. 25-30.

Damage: Sulfur dioxide
Sensor: Color-IR photography
Area: Kamloops Area, British Columbia

Sulfur dioxide damage which occurred in 1971 was photographed in 1975 and 1976 and field checked. There was no significant difference in height growth of conifers except a 50% reduction in diameter growth in the heavy damage zone. Photo interpretation of affected zones has revealed a 25% top dieback among cottonwood in the heavy damage zone, and 14%, 3% and 1% dieback in the medium, light and no damage zones, respectively.

128. Murtha, Peter A., A.H. Johnson and R.M. Strang, 1980

Photointerpretation of fire damage to trees in ponderosa pine/bunch- grass community

Proceedings of the Sixth Canadian Symposium on Remote Sensing. 1980, May 21-23. Halifax, Nova Scotia. Thomas T. Alföldi *Ed.* Canada Centre for Remote Sensing. pp. 351-359.

Damage: Fire
Sensor: Color-IR large-scale photography
Area: Kamloops area, British Columbia

Test-burn plots measuring 25 m x 30 m were analyzed on 1:1000 scale color-IR transparencies and ponderosa pine trees were classified accord-

ing to ratings by the watercan analogs (WCA) which integrate and quantify the heat pulse of the site. For interpretation of fire-related tree damage, the authors suggest the use of optical densitometry. The results indicate that a combination of visual photo interpretation and calculated spectral ratio deviations provide a reliable technique for determination of fire impact on trees in the rangeland plant community.

129. Myers, Brian J. 1978

Remote sensing of vegetation damage to assess the effectiveness of prescribed burning in Australia

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 497-509

Damage: Effectiveness of prescribed burning
Sensor: Color-IR photography
Area: Southeastern Australia

The results of a trial using color-IR 70-mm aerial photography at scales of 1:15000 and 1:2500 to detect and map vegetation damage as an indicator of the effectiveness of prescribed burning for management purposes is reported. Mapping of burned boundaries was accomplished on 1:15000 color-IR transparencies with 83% accuracy at a cost of $0.27 per ha. On a combined use of 1:15000 and 1:2500 transparencies the accuracy was 93% at a cost of $0.39 per ha.

130. Myers, B.J. and T. Bird, 1978

Detection of a crown dieback in Australian Eucalypt forests on large scale aerial photographs

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 291-297

Damage: Crown dieback
Sensor: Color and Color-IR 70-mm Aerial photographs
Area: Australia

A trial of different films and scales was conducted in native regrowth forests in Tasmania to evaluate the effectiveness of various combinations for detection of a eucalypt disease manifested by crown dieback. Eight film/scale combinations were used: 1:2000 and 1:4000 on color-IR, and 1:1000, 1:2000, 1:3000, 1:4000, 1:6000 and 1:8000 on color negative film. Contact size color transparencies were used for rating individual trees into one of 4 dieback classes. Healthy (less than 20% crown dieback), Affected (20-40% dieback), Advanced (40-99%), and Dead (leafless). Interpretation criteria were color, texture, and presence of dead branches. Recommended scale for experienced interpreters is 1:4000, and 1:3000 for less experienced interpreters. The 1:2000 scale is larger than required.

131. Neubert, Robert W. 1969

Sick trees

Photogramm. Eng. 35:472-475

Damage: Douglas-fir root rot (*Poria weirii*)
Sensor: PRT-5 IR heat sensing radiometer and video recorder with TV camera
Area: Douglas-fir stands in Oregon and Washington, USA

Experimental work conducted by John Wear to detect root rot infestation in Douglas-fir stands using airborne heat sensing device and video recorder is described. An Ampex CC-6007 closed circuit TV camera with a wide-angle lens and a Barnes Engineering PRT-5 infrared radiometer were used in a helicopter to measure IR emissions from trees. Infrared rays were electronically transposed into electrical input in the voltmeter and displayed on a 9-inch TV monitor showing different temperatures for healthy and diseased trees.

132. Olson, Charles E., Patricia J. Sacks, John A. Witter and Lisa A. Bergelin, 1982

Spruce budworm damage assessment with 35 mm air photos. A training manual.

The University of Michigan, School of Natural

Resources, Remote Sensing Laboratory, Ann Arbor, Mich. Report No. UMSNR/RSL 82-1A, 32 pp + Appendix, 8 pages with color stereograms, exercises and answers.

Damage: Spruce budworm
Sensor: Color aerial photographs (35-mm)
Area: Michigan, U.S.A.

This manual describes practical application of 35-mm aerial photography for assessing forest damage. Included are good quality color stereograms with exercises for species identification and defoliation ranking. Answers to exercises are provided in the Appendix. Authors recommend slower films (ASA 64) which provide a better definition of shaded areas than the high speed films (ASA-200).

133. Puritch, George S. 1981

Nonvisual Remote Sensing of trees Affected by Stress. A review

Can. For. Serv. For. Tech. Rep. 30. 38 p.

Damage: N/A
Sensor: N/A
Area: N/A

Research dealing with the nonvisual remote sensing of stress-affected trees is reviewed and arranged according to specific stress factors: water, insects, fungal disease, air pollution, chemical, and mechanical. The interaction of the visible, near-infrared, far-infrared and thermal regions of electromagnetic radiation with the foliage and the resulting effect on spectral reflectance is covered in detail. Over 100 references are listed.

134. Rohde, Wayne G. 1971

Multispectral enhancement of disease in forest stands

Proceedings of the Third Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1971, March 2-4. University of Florida, Gainesville, Florida. Abraham Anson *Ed.* American Society of Photogrammetry. pp. 131-143

Damage: Vegetation Stress
Sensor: Multispectral Enhancement
Area: N/A

A color-combining process to simulate normal color and color-IR films from black-and-white negative transparencies was used for the enhancement of diseased trees and improved detection of stress in vegetation. The wavelength bands from 0.4 to 2.6 micrometres used in creating the false color films were selected on the basis of laboratory reflectance data.

135. Rohde, Wayne G. and Charles E. Olson, Jr. 1970

Detecting tree moisture stress

Photogramm. Eng. 36:561-566

Damage: Moisture stress
Sensor: IR line scanner and four 70-mm cameras
Area: Rose Lake Wildlife Research Centre near Lansing, Michigan

To create locations of known moisture stress, several oak, red maple, and balsam poplar within the test plots were girdled with a chain saw. Day and night thermal-IR imagery in the 8- to 14-micrometer region was obtained in May. In July, day and night thermal-IR images were obtained in the 8 to 14, and 4.5 to 5.5 micrometre regions. Color and black-and-white (both panchromatic and IR) photographs of the test area were also obtained in July. Girdled plots were detectable on all IR imagery obtained in July. However, girdled trees would not have been detected on any night thermal-IR images if their exact locations had not been previously known.

136. Sapp, C. Daniel 1978

Detecting the effects of sulphur dioxide emissions on vegetation by remote sensing

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 381-400

Damage: Sulfur dioxide
Sensor: Various (photographic and non-photographic)
Area: Tennessee, Alabama, Kentucky, USA

Effects of sulfur dioxide emission from four coal-burning plants on vegetation was investigated by remote sensing techniques: spectroradiometry, close range photography of affected plants in the laboratory, aerial photography, and multispectral scanner imagery. Color-IR aerial photography was found the most useful sensor. Digital analysis of airborne MSS data from altitudes of 500m, 2000m and 3660m indicate that the optimum height for detecting sulfur dioxide effects on agronomic species is 2000m. Effects on forest species can be detected at higher altitudes. Optimum channel combination in digital analysis was 4, 7, 8 and 9, or 4, 6, 7, and 8.

137. Schultz, Mark, E. 1978

Remote analysis of forest tree mortality in California

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 335-354

Damge: Tree mortality (root rot, bark beetles)
Sensor: Normal color aerial photography
Area: California, USA

Tree mortality caused by the root pathogen *Fomes annosus* and by a bark beetle complex was studied on true color aerial photographs at a scale of 1:8000. The average photo-detectable centre at that scale was 0.14 ha. Color-IR photographs were not as useful for interpreting weakened trees as normal color taken under an overcast.

138. Scherrer, H.U., H. Fluehler and B. Oester. 1979

Pine damage rating on medium and large scale infrared aerial photographs

Proceedings of the Seventh Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1979, May 15-17. University of California, Davis, California. American Society of Photogrammetry, pp. 151-160

Damage: Pine mortality due to stress
Sensor: Color-IR aerial photography
Area: Rhone Valley, Switzerland — 426 km²

A network of 781 quarter-hectare sampling plots were analyzed on 1:13 000 scale color-IR aerial photographs using an autograph Wild B8 stereo plotter. Nine partially correlated variables were rated on each plot: elevation, exposure, topography, stand type, canopy coverage, age class, site index, pine mortality, and age of dead pine trees. Spatial and frequency distributions of individual variables were analyzed. Tree vigor was evaluated on large-scale (1:1900) color-IR-70 mm aerial photography and compared with the ground rating. Up to five classes of tree vigor, expressed as health index, may be reliably distinguished.

"A stratified sampling strategy combining these two intensive procedures appears to be a viable and promising approach for forest damage assessment."

139. Seevers, Paul M. 1981

Consideration of using color infrared photographs for vegetative interpretation

Proceedings of the Eighth Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1981, April 21-23. Luray, Virginia. American Society of Photogrammetry. pp. 45-49.

Damage: General
Sensor: Color-IR film
Area: N/A

Since tissue damage in most crops has to be relatively severe before it becomes detectable on color-IR film and visible to human eye, the author concludes that the previsual detection of crop damage is not likely on color-infrared film. "Furthermore, the perceptability of color contrast by the human eye tends to be a deterrent to visual detection of plant symptoms, both in the field and in the interpretation of color-IR photographs."

140. Smith, Richard S. Jr. and Bruce Roettgering. 1982

A biological evaluation of three years of pest-caused tree mortality on the San Bernardino National Forest

Forest Pest Management, Pacific Southwest Region, Report No. 82-4, 22 pp.

Damage: Insect/root disease (pest complex)
Sensor: Aerial photography (Ektachrome MS 2448), RMK 8 1/4"
Area: 470 km², San Bernardino National Forest, California

Color aerial photography at a scale of 1:8000 was used under 4X to 8X magnification for a stereoscopic analysis of photo plots. The photo interpreter counted dead trees, which appeared yellow to sorrel color, and estimated species and size class. To verify that the trees had died during the year before photography, a check was made of the dead trees using photographs taken the preceding year.

All dead trees detected on the photo plots were visited on the ground within a few months following photography for verification and collection of additional data.

141. Stevens, Alan R. 1972

Application of small format color and color infrared aerial photography to Dutch elm disease detection

Proceedings of the Annual Meeting of the American Society of Photogrammetry. 1972. pp. 349-357.

Damage: Dutch elm disease
Sensor: 35-mm handheld camera with color and color-IR film
Area: Residential area of Madison and the University of Wisconsin nursery

The study involved spectral reflectance and densitometer studies of Ektrachrome, Agfachrome and Ektachrome IR oblique aerial photography obtained with hand-held 35-mm cameras, and interpretation of tree crowns infected by Dutch elm disease. Previsual detection of Dutch elm disease on color and color-IR film is unreliable.

142. Stephens, Peter, R. 1976

Comparison of color, color infrared and panchromatic aerial photography

Photogramm. Eng. Remote Sens. 42:1273-1277

Damage: General vegetation types and condition, erosion
Sensor: Color, color-IR and Pan 35-mm aerial photography
Area: South Ruahine Mountains, New Zealand

Color, color-IR, and panchromatic aerial photography taken with 35-mm cameras at the scale of 1:18 000 are compared. The capability of the three films is assessed in regard to their effectiveness to distinguish geologic features, seepage areas, eroded surfaces, vegetation types and condition, and drainage pattern. Of the three film types, color-IR was the most effective.

143. Stocks B.J., P.H. Kourtz and J.B. Todd. 1980

Satellite mapping of spruce budworm-killed Balsam Fir in Ontario

Proceedings of a Remote Sensing Symposium sponsored by the Ontario Ministry of Natural Resources and the Great Lakes Forest Research Centre. 1979, October 22-25. Toronto, Ontario. Canadian Forestry Service. pp. 125-128.

Damage: N/A
Sensor: N/A
Area: N/A

The development of a technique for delineating areas of high balsam fir mortality from satellite imagery is outlined. The mapping of high mortality areas in this fashion will assist forest fire managers in allocating men and resources accordingly.

144. Talerico, Robert L., John E. Walker and Thomas A. Skratt. 1977

Progress Toward Quantifying Insect Defoliation with Advanced Photometric Methods

Proceedings of the Sixth Biennial Workshop on Aerial Color Photography in the Plant Sciences and Related Fields. 1977, August 9-11. Fort Collins, Colorado. American Society of Photogrammetry. pp. 60-71.

Damage: Defoliation by Gypsy moth
Sensor: Color and color-IR photography and LANDSAT photometric calibration of IR/R reflectance
Area: Pennsylvania, USA

Advanced remote sensing techniques including photometric interpretation, in which apparent densities of objects imaged on the film were corrected for all periferal effects to provide true reflectance values are described. High altitude (1:80 000) color IR photography and Landsat imagery was used to develop a quantitative defoliation index from photo-reflectance measurements and to generate foliage stress maps. The authors conclude that LANDSAT data are better than high altitude color-IR film for mapping defoliation.

145. Talerico, R.L., J.E. Walker and T.A. Skratt, 1978

Quantifying gypsy moth defoliation

Photogramm. Eng. Remote Sens. 44:1385-1392

Damage Gypsy moth defoliation
Sensor: Color and color-IR photography
Area: 182 km² northwest of Mifflinburg, Pennsylvania

Color and color-IR aerial photography at scales of 1:15840, 1:31680 and 1:4000 was flown in May, June and July. The film was calibrated and ten Macbeth densitometer readings were made for three spectral bands - red, green and IR to produce a density value for data points. The scene color standard (SCS) was used as an objective method for measuring insect defoliation from color-IR photography. This photo-derived defoliation measure includes terms for IR/R reflectance, green reflectance at maturity, and average red, green and IR reflectance of the crown. The correlation of measurements by the SCS analysis with ground observations of defoliation was $R^2 = 0.78$.

146. Thompson, David R. and Oscar A. Wehmanen, 1979

Using Landsat digital data to detect moisture stress

Photogramm. Eng. Remote Sens. 45:201-207

Damage: Moisture stress (Agriculture)
Sensor: LANDSAT digital data
Area: USA Great Plains, USSR (Siberia) and Australia

The LACIE (Large Area Crop Inventory Experiment) 5 by 6 nautical mile sampling frames randomly located over the Great Plains wheat growing region were used for detecting and monitoring vegetative water stress using transformed LANDSAT digital data. The technique, Green Index Number (GIN), uses LANDSAT digital data from 4 by 6 mile sampling frames to indicate when the vegetation within the frame is undergoing drought. At known growth stages for wheat, frames were classified as drought or non-drought areas. The results were compared to a weekly ground-based index (crop moisture index) provided by U.S. Dept. of Commerce. This comparison demonstrated a high degree of agreement between the 18-day remote sensing technique and the ground-based weekly data. A similar method was used to produce maps of parts of USSR and Australia showing the areas of vegetation undergoing stress and adequate moisture conditions.

147. Tonelli, Arnaldo M. 1978

The use of vegetation as a transducer for environmental pollution

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 115-126

Damage: Sulfur dioxide
Sensor: Thermal-IR
Area: Northern Italy

This paper describes the use of bands 1-2 and 9-11 thermography for mapping and monitoring the effect of sulfur dioxide distribution around a power plant and for studying the influence of magmatic gases on vegetation in volcanic areas.

148. Tueller, Paul T. 1979

Some aspects of the use of dichotomous keys to aid in the interpretation of color aerial photographs for vegetation mapping

Proceedings of the Seventh Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. 1979, May 15-17. University of California, Davis California. American Society of Photogrammetry. pp. 189-200

Damage: N/A
Sensor: N/A
Area: N/A

The use of photo interpretation keys in the analysis of vegetation patterns on aerial photographs is described. Two types of photo interpretation keys (a selective key and an elimination (dichotomous) key) are discussed. Described example of a key for interpretation of natural vegetation described in this paper may be modified for a use in photo interpretation of forest damage.

149. Ulliman, J.J. and D.W. French. 1977

Detection of oak wilt with color IR aerial photography

Photogramm. Eng. Remote Sens. 43:1267-1272

Damage: Oak Wilt
Sensor: Color-IR aerial photography
Area: About 100 ha in Minnesota, USA (near North Oaks)

Color-IR aerial photography with various filters was tested at scales of 1:6000, 1:12 000, 1:15 840, 1:24 000 and 1:31 680 for the detection of oak wilt infection centers. The accuracy of detection increases with scale. Up to 100% detection was achieved with the 1:24 000 scale and Ektachrome IR/Wratten No. 21 filter. Commission errors (interpreting dead trees or dead branches as oak wilt infection centres) remains a problem.

150. Vaas, P.A. and J.L. van Genderen. 1978

Monitoring environmental pollution by remote sensing

Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment. G. Hildebrandt and H.J. Boehnel *Eds.* 1978, July 2-8. Freiburg, Federal Republic of Germany. International Archives of Photogrammetry. 22:2125-2142.

Damage: Vegetation stress caused by air pollution
Sensors: Multiband camera system
Area: Reference to various studies

The paper outlines the various types of environmental pollution which may be studied by remote sensing (smoke and dust, sulfur dioxide, lead, photochemical smog, fluoride, organic wastes, eutrophication, synthetic chemicals, etc.).

151. Wallen, V.R. and L.E. Philpotts, 1971

Disease assessment with IR-color

Photogramm. Eng. 37:443-446

Damage: Blight in beanfields
Sensor: Color-IR photography
Area: Near Hensall, Ontario

Color-IR photography at scales of 1:3600 and 1:8400 was used for evaluation of diseased plants on 20 fields. The infected areas were traced onto a cellulose acetate sheet coated with Krylon. The sheet was then placed on 4x4 foot paper and scanned on an IMB drum scanner, and the information recorded on magnetic tape. One square inch of the sheet is subject to 62 500 recordings

and, depending on the photographic scale, each 1.4 to 7.8 square feet of a given field is scanned with the technique. Yields of the field were also recorded in an attempt to obtain a disease-yield loss evaluation.

152. Wear, J.F., R.B. Pope and P.W. Orr, 1966

Aerial Photographic Techniques for Estimating Damage by Insects in Western Forests

U.S. For. Serv. Northwest. For. Range Exp. Stn. 79 pp.

Damage: Insects — General
Sensor: Aerial photography
Area: N/A

This manual describes the use of aerial photographs in two principal types of surveys: 1) sampling to estimate amount of damage or mortality, 2) complete coverage to locate the dead or damaged trees for salvage operations. The double sampling with regression method and modifications for specific insect problems is described and illustrated.

153. Weber, F.P. 1971

Applications of airborne thermal remote sensing in forestry

Application of Remote Sensors in Forestry. Joint Report by the Working Group on Application of Remote Sensors in Forestry. International Union of Forest Resource Organizations, Section 25: 75-88.

Damage: Forest fire, insects and diseases — general
Sensor: Thermal-IR
Area: Idaho, South Dakota

The use of an airborne IR detection system is described. The system, while very useful in the discovery and location of latent fires, did not provide desired results in the previsual identification of beetle-infested or disease-infested trees. The best detection results were obtained with a 3-channel combination of two reflective IR channels with one thermal channel.

154. Weber, Frederick P. 1976

Forest stress detection — Ponderosa pine mortality from mountain pine beetle

Evaluation of Skylab (EREP) data for forest and rangeland surveys. U.S. For. Serv. Res. Pap. PSW 113/1976. p. 55-63

Damage: N/A
Sensor: N/A
Area: N/A

Data from the Skylab Earth Resource Experiment Package were examined monocularly or stereoscopically using a variety of magnifying devices. Land use, forest types, physiographic sites, plant communities and forest stress were interpreted and mapped at sites in Georgia, South Dakota and Colorado. Microdensitometric techniques and computer-assisted data analysis and sampling procedures were developed and tested against ground truth. Results indicate that only Skylab S 190 B color photographs are good for classification of forest and non-forest land (90-95% correct). Both visual and mocrodensitometer techniques can separate range plant communities at the Region level (Ecoclass system) with over 90% accuracy. Only mountain pine beetle infestations more than 26m long could be detected.

155. Weber, F.P. and F.C. Polcyn. 1972

Remote sensing to detect stress in forests

Photogramm. Eng. 38:163-175

Damage: Insects, root rot and oxidant air pollution
Sensor: MS optical-mechanical scanner
Area: Examples from various parts of USA

The application of airborne MSS for previsual detection of damage from insect infestations, disease organisms, and oxidant air pollution is described. Optical-mechanical line scanners flown over instrumented ground test sites in several different forest communities collected 18 discrete channels of remote sensing data between 0.4 and 13.5 micrometers. Reflective and emissive differences among stressed trees were well

documented from ground measurements. The University of Michigan's MS optical-mechanical scanner and ground processing techniques were tested in terms of how they perform in detecting plant stress.

156. Weber, Frederick P., Edwin H. Roberts, Thomas H. Waite, 1975

Forest Stress Detection

Evaluation of ERTS-1 Data for Forest and Rangeland Surveys. U.S. For. Serv. Res. Pap. PSW 112/1975. Robert C. Heller *Technical Coordinator.* p. 44-63

Damage: Mountain pine beetle infestation
Sensor: ERTS-1 black-and-white and color composite transparencies, enlargements and computer-assisted mapping
Area: Black Hills test site (10 200 km²) in South Dakota and Eastern Wyoming

Three visual interpretation methods and a computer assisted analysis of ERTS-1 CCT were used: 1) Color composite and black-and-white single-channel 1:1 000 000 scale were viewed with Bausch and Lomb Zoom 70 microscope enlarging to a scale of 1:83 000, 2) use of a Variscan rear-projection viewer magnifying to a scale 1:333 000 and 1:83 000 and, 3) Projection of ERTS transparencies with an overhead projector and viewing at the scale of 1:83 000.

In the computer-assisted analysis of CCT, two classification systems were used for mapping dead and dying pine trees: one devised by the PSW group and the other devised by LARS. Actual scale of the display was 1:24 000.

Regardless of the interpretation method used, the infestation areas were not detected. The visual interpretation has failed to detect several infestations over 300m in length. The computer assisted LARS classification did not identify any dead pine.

157. Winquist, E. and J.H. Vanderbrink. 1982

Application of remote sensing to mountain pine beetle management in southern Alberta

Proceedings of a Seminar on Uses of Remote Sensing in Forest Pest Damage Appraisal. 1981, May 8. Edmonton, Alberta. Can. For. Serv. North. For. Res. Cent. Inf. Rep. NOR-X-238: 25-29.

Damage: N/A
Sensor: N/A
Area: N/A

The use of color and color-IR photography for monitoring the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) infestation in southern Alberta is described. Authors expressed a preference for color film because of the difficulty they had in distinguishing mountain pine beetle-infested stands from overmature white spruce and balsam fir. Color film also permitted better shadow penetration in the mountainous areas, but there was a problem with haze penetration at higher altitudes.

158. Wenderoth, Sondra, 1975

Narrow Band Multispectral Photography for Previsual Detection of Stress in Vegetation

Proceedings of the Workshop for Environmental Applications of Multispectral Imagery. 1975, November 11-13. Fort Belvoir, Virginia. U.S. Army Topographical Laboratory. pp. 27-33.

Damage: Stress in forest stands and crop vegetation
Sensor: Narrow band multispectral photography
Area: Examples from various areas

Narrow band (7 to 40 nm) multispectral photography with selected precise filter band widths was employed to detect stress in vegetation. Comparison color and color-IR photography was flown simultaneously at altitudes from 1000 to 20 000 feet. While the tripack emulsions were unable to indicate the stressed vegetation before it was visible to the human eye, the narrow band multispectral system was capable of previsually

detecting stressed corn plants, diseased avocado trees (root rot) and infected elms, and of predicting the extent of stress by the image color.

159. Williams, David R. 1978

Applications of remote sensing to vegetation injury caused by air pollution

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978, Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 529-543

Damage: Sulfur dioxide
Sensor: Color-IR photography
Area: Missouri and New Hampshire, USA

Two separate cases of vegetation damage caused by sulphur dioxide emission were investigated on color and color-IR photography at a scale of 1:12000. Vegetation exposed to sulfur dioxide exhibited injury symptoms and was classified as acute or chronic depending upon the extent of the injury, and the time and dosage of the pollutant. A stereoscopic analysis of tone, texture, size, shape, and other photo characteristics, complemented with ground data, was used for identification of affected trees. Injured trees exhibited a consistent yellow tone in contrast to red or magenta tone of healthy trees.

160. Williams, Darrel L. and Mark L. Stauffer, 1978

Monitoring gypsy moth defoliation by applying change detection techniques to Landsat imagery

Proceedings of the Symposium on Remote Sensing for Vegetation Damage Assessment. 1978. Feb. 14-16. Seattle, Washington. American Society of Photogrammetry. pp. 221-229

Damage: Gypsy moth
Sensor: LANDSAT MSS
Area: N/A

The need for development and evaluation of digital image processing techniques that could "facilitate the assessment of the intensity and spatial distribution of forest insect damage in northwestern U.S. forests using remotely sensed data from LANDSAT 1, 2 and C" is discussed. Only the life cycle of gypsy moth is described and, due to the very weak funding of this project, there are no definitive results to report at this time.

161. Wilson, Ralf A., Stanley N. Hirsch, Forrest H. Madden and B. John Losensky, 1971

Airborne infrared forest fire detection system: Final report

U.S. For. Serv. Res. Pap. INT-93. 99 pp.

Damage: Forest fire
Sensor: Airborne IR mapper
Area: Northwestern USA

The basic requirements for an airborne infrared forest fire detection system are described. Results from attempts to detect hot fire targets in natural forest background in 13 test sites are discussed.

162. Zirm, K. 1978

Measurement of environmental stress in mountain areas caused by tourism

Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment. G. Hildebrandt and H.J. Boehnel *Eds.* 1978, July 2-8. Freiburg, Federal Republic of Germany. International Archives of Photogrammetry. 22: 2117-2123

Damage: Environmental stress caused by tourism
Sensor: Color IR aerial photography
Area: Alpine areas (Saltzburg and Tirol) Austria

Two well known high mountain skiing places in Austria were studied on color-IR aerial photographs for the changes on ski slopes produced by winter sport activities.

Other Useful References (Bibliographies, Manuals, Textbooks)

163. American Society of Photogrammetry, 1983

Manual of Remote Sensing, second edition, Falls Church, Virginia. Two volumes, 2724 pp. 2072 illustrations (279 color).

Editor-in-Chief Robert N. Colwell, 200 contributors.

The most extensive remote sensing manual covering the entire spectrum of remote sensing science in 36 chapters. A comprehensive bibliography included in each chapter.

164. American Society of Photogrammetry, 1981

Manual of Photogrammetry, 4th Edition, Falls Church, Virginia. 1056 pp. 866 illustrations.

165. American Society of Photogrammetry, 1980

Complete index to Photogrammetric Engineering and Remote Sensing, Volumes I-XLV, 1934-79. 145 pp + pp. 1657-1675.

166. American Society of Photogrammetry, 1969

Manual of Photographic Interpretation, Washington, D.C. 868 pp.

167. American Society of Photogrammetry, 1968

Manual of color aerial photography, Washington, D.C. 550 pp. + color illustrations.

168. Avery, T. Eugene, 1975

Interpretation of aerial photographs. Burges Publishing Co., Minneapolis, Minnesota. 553 pp, illustrations.

169. Canada Air Board, Intelligence Branch (no date)

Selective bibliography on forestry reconnaissance, photography, and forest fire protection by air. Air Board Library, Ottawa.

This is the first Canadian bibliography on remote sensing published in the mid 1920s.

170. Hildebrandt, G. 1969

Bibliographie des Schriftums auf dem Gebiet der forstlichen Luftbiltdauswertung, 1887-1968 (Bibliography of forestry applications of aerial photography) The University of Freiburg, West Germany, 307 pp (in German). Section 587.6 x 4 Forest Protection, Damage (pp 197-205) lists 82 titles on forest damage.

171. Henninger, J. and G. Hildebrandt, 1980

Bibliography of publications on damage assessment in forestry and agriculture by remote sensing techniques. 2nd enlarged edition, April 1980. University of Freiburg, West Germany. 280 pp.

Forestry part has 579 entries plus 26 in the Appendix. Index by key words an authors.

172. Kasischke, Eric C. (Editor) 1981

Proceedings of the International Symposium on Remote Sensing of Environment: Indexes and Abstracts. Environmental Research Institute of Michigan, Ann Arbor, Michigan.

Two volumes covering 1700 scientific and technical papers from 28-volume proceedings 1962-1980. Volume I, Index, Volume II, Abstracts in Chronological order.

173. Lillesand, Thomas M. and Ralf, W. Kiefer, 1979

Remote sensing and image interpretations. John Wiley & Sons, New York-Toronto. 426 pp.

174. Myers, Brian J. and Ian E. Craig, 1980

Bibliography of remote sensing in forestry 1950-1978. Division Report No. 5. Division of Forest Research, Commonwealth Scientific and Industrial Research Organization, Canberra, Australia. 150 pp.

Section on Forest Injuries and Protection (pp. 101-113) is divided into 6 subsections: General, Injuries from Inorganic Agencies, Forest fire, Harmful plants, Virus and fungal diseases, Damage by animals and insects, and Damage by man. Included are 190 titles, some on general forestry or brief notes.

175. Murtha, P.A. 1969

Aerial photographic interpretation of forest damage: an annotated bibliography. Can. Dept. of Fisheries and Forestry, Forest Man. Institute, Information Report FMR-X-16, Ottawa, Ontario. 76 pp. A total of 229 titles: 58 on spectral reflectance, 10 on tree species and forest type identification, 41 on cameras, films, filters, and aerial photographic techniques, 40 on photo interpretation techniques, 24 on miscellaneous and general references and 56 titles on forest damage (48 on forest damage detection and 8 on forest damage evaluation).

176. National Academy of Sciences, 1970

Remote sensing with special reference to agriculture and forestry. Committee on Remote Sensing for Agricultural Purposes, Agricultural Board, National Research Council, Washington, D.C. 424 pp.

Nine chapters: 1. Uses, potentialities, and needs in agriculture and forestry; 2. Imaging with photographic sensors; 3. Imaging with nonphotographic sensors; 4. Application of remote sensing in agriculture and forestry; 5. Physical and physiological properties of plants; 6. Soil, water and plant relations; 7. Field spectroscopy; 8. Sampling and statistical problems; 9. Research needs: the influence of discrimination, data processing and system design. Over 200 references.

177. Nelson, B.C. 1965

An annotated bibliography of "spectral analysis and aerial photographic application to plant species and disease detection". Part of the 1965 Honors Program Report, Dept. of Forestry, Iowa State University.

178. Paine, David P. 1981

Aerial photography and image interpretation for resource management, John Wiley & Sons, New York. 571 pp and 253 illustrations. Parts Three (Photo interpretation) and Four (Forest inventory) include some useful data on forest damage appraisal.

179. Polskie Towarzystwo Geograficzne-Sekcja Fotointerpretacji, 1965

Bibliografia Fotointerpretacji (Polish Geographical Society, Section on photo interpretation — Bibliography of photo interpretation, the University of Warsaw Press, Warsaw. 128 pp. (in Polish). Contains references to worldwide literature for the period of 1946-1964. Has a good coverage of Russian literature.

180. Raizer, P.Y. 1959

Aerometody i ih primenenie. Bibliograficheskiy ukazatel 1856-1955. (Aeromethods and their application. Bibliographical Index 1856-1955). Akademia nauk USSR, Moscow. 754 pp. (in Russian).

181. Soil Conservation Society of America, 1982

Remote sensing for resource management, edited by Chris J. Johansen and James L. Sanders. Ankeny, Iowa. 657 pp.

A collection of 53 papers divided into 10 parts. Part 3: Remote Sensing Applications to Vegetative Resources includes a paper by Peter A. Murtha; Detecton and analysis of vegetation stress (pp 141-158).

182. Spurr, S.H. 1956

Forest photogrammetry and aerial mapping. A Bibliography 1887-1955. School of Natural Resources, University of Michigan, Ann Arbor, Mich., 66 p.

775 titles listed in ten sections: I — 1887-1918, II — 1918-1944, USA; III — 1918-1944, Canada; IV — 1918-1944, Europe; V — 1918-1944, Other parts of the World; VI — 1944-1955, USA; VII — 1944-1955, Canada; VIII — 1944-1955, Europe; IX — 1944-1955, Other Parts of the World; X — Unpublished Theses and Reports, USA and Canada.

183. Steiner, Dieter, 1970

Annotated bibliography of bibliographies on photo interpretation and remote sensing. Photogrammetria 26:143-161

List of 254 references + index.

184. Steiner, Dieter and Thomas Guttermann, 1966

Russian data on spectral reflectance of vegetation, Soil and rock types, Final Technical Report, Dept. of Geography. University of Zurich, Switzerland. 232 pp.

A survey of Russian literature on spectral reflectance with 11-page bibliography and index to geomorphological, pedological and botanical terms.

185. Strandberg, Carl H. 1967

Aerial discovery manual. John Wiley & Sons, 249 pp. A training manual for air photo analysis of land, vegetation and water resources.

186. U.S. Corps of Engineers, 1966

Bibliography of remote sensing of resources. Prepared for Earth Resources Survey Program, Space Applications Programs, NASA, Ft. Belvoir, Va. 40 pp.

187. Wenderot, Sondra and Edward Yost, 1974

Multispectral photography for Earth resources. Science and Engineering Research Group, C.W. Post Center, Long Island University, Greenvale, N.Y. 320 pp + color plates. A good reference on multispectral photography. Included are examples of vegetation damage.

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